Research Note 80-20

AD A100 185

QUASI-ALGORITHM
METHODS AND TECHNIQUES FOR SPECIFYING
OBJECTIVE JOB/TASK PERFORMANCE
REQUIREMENTS

Felix F. Kopstein and Edward H. Kingsley

Institute for Psycho-Logic

Guy L. Siebold

ARI

U. S. Army

Research Institute for the Behavioral and Social Sciences

July 1978

Approved for public release; distribution unlimited.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Research Note 80-20	2. GOVT ACCESSION NO. AD-A100 435	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) QUASI-ALGORITHM METHODS AND TECHNIQUES FOR SPECIFYING OBJECTIVE JOB/TASK PERFORMANCE REQUIREMENTS		5. TYPE OF REPORT & PERIOD COVERED Final Technical Report, Jan - Aug 1978
		6. PERFORMING ORG. REPORT NUMBER TR-78-1
7. AUTHOR(s) Felix F. Kopstein ~~and~~ Edward H. Kingsley, IP-L Guy L. Siebold, ARI		8. CONTRACT OR GRANT NUMBER(s) DAHC19-78-C-0004
9. PERFORMING ORGANIZATION NAME AND ADDRESS Institute for Psycho-Logic 595 Barton Lane Strafford, PA 19087		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2Q161102B74F
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Research Institute (PERI-IS) 5001 Eisenhower Avenue Alexandria, VA 22333		12. REPORT DATE July 1978
		13. NUMBER OF PAGES 56
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 18 ARI 19 RN-		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

The Contract was monitored technically by Pauline T. Olson, ARI.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Job/Task Analysis	Human Performance	Personnel Classification
Algorithms	Training	Occupational Engineering
Mathematical Models	Education	Artillery
Human Factors	Assessment	Fire Direction Center

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An exploratory project was conducted to assess the practical feasibility of establishing objective, empirically verified task descriptions or specifications (TS). Also, using the developed TS as a foundation, the possibility of erecting data structures (models) on them were investigated as were mathematical techniques for extracting information from these models. In Part I the concept of quasi-algorithms is introduced and applied in task analysis. An account is given of the development and successful verification procedures

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

i

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract cont.

for quasi-algorithmic TS of a number of Field Artillery Fire Direction Center activities. These TS are listed. Improved procedures for routine development are outlined. Diverse uses of quasi-algorithmic TS, as such, are discussed. In Part II a mathematical model for structuring TS is presented. Abstract representation of TS in terms of attribute vectors is explained. A binary vector model is developed with reference to a TS from Part I. The concepts of dominance and cardinality are introduced, and it is shown how they structure any TS or set of TS. Applications to training, task taxonomy, duty assignments, career fields, etc. are outlined. The improved sensitivity of a model employing fuzzy subset theory is explained briefly.

Research Note 80-20

QUASI-ALGORITHM
METHODS AND TECHNIQUES FOR SPECIFYING OBJECTIVE JOB/TASK PERFORMANCE REQUIREMENTS

Guy L. Siebold
Army Research Institute

Submitted by:
Robert M. Sasmor
Director, Basic Research

A

Approved by:
Joseph Zeidner
Technical Director

U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES
5001 Eisenhower Avenue, Alexandria, Virginia 22333

Office, Deputy Chief of Staff for Personnel
Department of the Army

Army Project Number
2Q161102B74F

Job/Task Analysis

FOREWORD

This report describes research conducted to explore the potential of quasi-algorithm methods and techniques for specifying objective job and task performance requirements. The report also presents a model for developing data structures compatible with the quasi-algorithm task specifications (TS). This research was performed by the Institute for Psycho-Logic (IP-L) under Contract DAHC19-78-C-0004 with the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI). This technological base research, done under Army project 2Q161102B74F, is of primary interest to job and task analysts and trainers.

Numerous Army functions such as training, personnel management, and manpower planning depend on detailed and accurate occupational information. Much of this information is produced by methodologies and techniques for describing and analyzing jobs and tasks. However, operational job/task description and analysis techniques suffer from various deficiencies -- arbitrary category systems, vague terms, restriction to individual level tasks, failure to relate jobs or tasks to unit missions, failure to order or integrate tasks, or failure to specify concrete task behaviors or performance standards. The exploration of the quasi-algorithm methodology included a look at its potential to overcome these deficiencies as well as to provide standard occupational information with reasonable cost and efficiency.

Quasi-algorithm task specifications (TS), as described in the report, are basically tables of sequential overt (observable) and covert (mental) behaviors necessary and sufficient to accomplish the tasks. A basic feature and advantage of TS is that they are objective behavioral specifications that both describe and prescribe the tasks. TS are expressed in a format and language readily understood by trainers and the soldiers who perform the tasks. TS are neither so abstract as to be divorced from everyday reality nor so fine grained as to be useful only to very specially trained analysts. In short, TS are not based on an arbitrary category system and do not use vague terms but do order task behavior and do specify concrete task behaviors.

Perhaps the strongest contribution TS methodology can make is to produce occupational information directly adaptable to training. Since TS describe and specify the actual behavioral sequences required for and resulting in successful task performance, training and curriculum development in terms of TS can promote uniform and efficient task performance.

When task performance is not successful, it means the TS was not followed. Because the TS is a series of sequential steps, the behavior of the unsuccessful task performer can be traced directly to the point in the sequence where the performer is having difficulty. In other words, TS are superb devices for the diagnosis or troubleshooting of learning problems. Because the precise step where the task performer is having difficulty can be located, TS usually indicate the appropriate remedy. For example, a soldier may be unable to perform a sequential step because he does not have the requisite knowledge, the necessary skill, or the appropriate physical or mental capability. The lack of knowledge or skill can be remedied by additional training through more fine grained TS. The lack of capability can only be remedied by the proper prior selection of soldiers for training (or perhaps by a change in equipment design or task procedure).

Besides being directly adaptable to curriculum development and the diagnosis of learning problems, TS methodology is compatible with the development of correspondence courses, soldier's manuals, skill performance aids, and skill qualification tests (SQTs). TS based SQTs can provide not only appropriate testing machinery but also the built-in capability for diagnosing performance problems. With the TS describing what needs to be done for successful task performance, the development of task and job standards becomes an easy next step whether the standard is measured by time to task completion, degree of error, or some other means. Again the diagnosis capability - to discover where performance falls below the standard - implies the appropriate type of remedy.

The creative use of TS might lead to their adaptation for the development of objective enlisted efficiency reports, to solidly founded job and MOS structures, and to better job assignment. TS are also advantageous in that they can be used for analysis at the individual or the group level of performance, although there appears some question as to whether TS can be used efficiently for a joint analysis of both the individual and group levels. As an additional plus, the method brings out the background knowledges and skills (elementarity) needed to perform a task or job. In this vein, the TS may be useful in "soft skill" description and analysis, especially since the method handles both overt and covert operations by treating a task as a process. A further benefit derives from the fact that the TS can be referenced to unit missions. Finally, TS are updatable, and their development per se requires no statistics.

Part II of the report presents a model for building data structures on TS. With TS forming a firm foundation for the data structures, much important information can be developed. For example, attributes associated with a particular task can be analyzed (as indicated in the report) and compared with attributes of other tasks in the same or a different MOS. These comparisons can shed considerable light on which

tasks should be structured together, where cross-training in tasks would be most efficient, and what members of a group would be the best substitute task performers.

The attribute data structure could be adapted to provide a myriad of important information for personnel management, training, and other major Army functions. For example, in terms of job structure, the tasks composing a job may require a coherent set of related attributes or may require a conglomeration of unrelated attributes. A job whose task attribute structure is of the latter type is more easily restructured than is a job whose task attributes are interrelated and similar. As another example, the concept of dominance (presented in the report) of tasks based on their attribute structure can be used to assess training priority or task criticality. Since TS and their attributes can be codified, their pertinent codes can be used to sort tasks, for example, by skill requirements, mission, ARTEPs, scenario, preferred type of training, or "softness." The codes can also be used to describe common tasks across duty positions, MOS, or pay grade in terms of measured attributes rather than ambiguous common terms or words.

As fruitful as the TS methodology may be, it is not without shortcomings. The time and trained manpower to create TS may not be available. The cost of continually updating TS may limit their usefulness to a few key jobs or tasks. The crucial TS concept of elementarity may prove to be quite loose and to beg the real questions, i.e., what, where, when, and how must one teach soldiers so that they will possess the elementarity needed to carry out the TS. The making of more fine grained TS at a lower level of elementarity may increase costs prohibitively so that TS may cost a reasonable amount to create at a level of elementarity possessed by school graduates but entirely too much at the level of detail needed by beginning students. In brief, the cost aspects of the TS methodology have not yet been assessed.

Individual and group streams of behavior, which are important to describe and analyze for certain purposes, do not appear to be encompassed by the TS methodology. Soldiers, individually and in groups, may be doing unrelated tasks simultaneously or in sequence. For example, a soldier may attend a race relations seminar in the morning, prepare an artillery surveyed firing chart in the early afternoon, and "paint rocks" later in the day. Where that soldier's job begins or ends is not clear. An occupational survey methodology, such as the Instructional Systems Development (ISD) model uses, can include questions about the time spent in non-MOS tasks. The TS methodology is not directly designed to collect this type of information.

For the TS methodology to provide extensive occupational information, attribute data structures must be built on the basic TS. These attribute structures, as envisioned in this report, are subject to many of the same criticisms as present techniques. Attribute categories may be quite

useful but also arbitrary. The usual problems concerning measurement and assignment of attribute values are bound to occur, fuzzy subsets (as presented in the report) notwithstanding. It may be difficult to handle the attribute structures across tasks and jobs of varying levels of elementarity, i.e., attribute values may change depending on the degree of elementarity at which a TS is written. The attribute measurement and applied coding scheme must be done by someone. As with factor ratings of training priority in the ISD model, questions will arise as to how, when, and by whom measurement and coding should be done. Further, what these possible attributes can or should be is neither determined, delimited, nor obvious. Finally, while TS may not require statistics in their development, attribute data structures built on the TS are likely to require a degree of statistical sophistication for their use. Thus, as with the manipulation and interpretation of task inventory data in the ISD model, the analysis of attribute data structures is likely to be confined to those who have the necessary amount of training, time, and machinery to use them.

One key problem in developing an Army occupational information system is the lack of explicit criteria by which a given methodology or mix of methodologies can be evaluated. Another key problem is the extent to which methodologies are underused. It is possible that a mix of the TS and the ISD task inventory methodologies would be quite valuable, but without specific evaluation criteria, the value of the mix cannot be determined. Further, measurement of their value, either individually or in a mix, is likely to be substantially hindered if the methodologies are as underused as the ISD methodology is currently.

Job description/analysis at the macro level and task description/analysis at the micro level must be seen as an interrelated whole. TS methodology may prove useful for task analysis and for specifying tasks to be used in building an ISD task inventory. The task inventory methodology, if fully utilized, in turn may provide most of the macroscopic information necessary for an overview of an MOS or for other purposes requiring aggregate information. It may be that a developed TS attribute structure can create the ties that bind the integrated system together. In any case, TS methodology appears to have great potential for use, individually or in combination with other methodologies, in providing important occupational information for training and other crucial Army functions.

ACKNOWLEDGMENT

We wish to acknowledge a great debt of gratitude to the following persons, whose warm, enthusiastic, intelligent and constructive support made this study possible:

SSG S. L. Davis
SFC R. Evans
SGM C. H. Fagg
LTC R. E. Klein
SFC P. Ives
CPT S. M. Lutz
SFC J. L. McFadden
GYSGT L. E. Nowak (USMC)
Mrs. P. Olson

TABLE OF CONTENTS

PART I.

QUASI-ALGORITHMIC TASK SPECIFICATIONS

PART II.

A MODEL FOR STRUCTURING TASK SPECIFICATIONS

PART I.
QUASI-ALGORITHMIC TASK SPECIFICATIONS

OBJECTIVE SPECIFICATION OF ACTIVITY

To go from any point A to some other point B on this earth, especially if one has never visited point B, one must have a map so as to plot the route. To aim an artillery piece at a target with even a slight chance of hitting it the location of gun and target must both be represented on a chart. To build a modern house -- its frame, plumbing, wiring, etc. -- without an accurate set of blueprints is virtually impossible. To diagnose the extent of -- say -- a brain tumor and to apply some discriminative, effective radiation treatment without x-ray photos of the affected area is unthinkable. In a slightly different vein: to alter the processing of, perhaps, a payroll by a computer without a copy of the relevant programs is quite impossible. In each case an accurate and reliable representation of reality is needed in order to cope with it. Lacking such an accurate representation we are forced to make do with incomplete or inaccurate approximations and to grope as the blind person does in the visual world.

Each kind of representation provides information not only as to a set of component elements (locations, objects, parts, anatomical features, processing operations), but also about their relationships to each other. The whole is greater than the sum of its parts, because the relation(s) on the set of parts constitutes additional information not contained in the sum itself. Any whole that is not conceived as an atomic entity has a structure. When we think in terms of terrain, buildings or even the human body the structure is one of physical objects. In the case of a computer program, however, the structure is not physical. Coded instructions usually go through a series of transformations into sequences of electrical impulses, and it is the information carried by these pulses which determines the course of action that the computer takes. The structure is the logical structure of logical objects (computer instructions). Instruction A precedes instruction B, and instruction B precedes instruction C or D. and so on. In the case of physical objects (e.g., a piece of machinery) lever A moves gear B so as to engage either gear C or gear D. Clearly, the abstraction of the actual object (machinery) in a drawing also represents a logical structure (synonym: organization), albeit diagrammatically.

The uses of an accurate representation of (logical) structure are, of course, legion. A succinct illustration of its importance can be given with reference to one of the major scientific discoveries of this century. As James Watson (1968) tells it, he and Francis Crick deliberately set out to discover the structure of the gene at a time when conventional wisdom held that the puzzle of genetics could be solved only through biochemistry. Once the structure of the gene had been established it became transparently clear how genetic replication is guaranteed. The structure proved to be the key to an understanding of the genetic process and to its effective control. In a sense the information stored by the gene (a relation of chemical components!) is the program for "re-computing" or re-constructing the individual.

In this introduction we have -- with some deliberation -- mixed apples and oranges. When we referred to maps, blueprints and x-rays we were referring to representations of static entities whereas programs for a computer, for example, are representations of dynamic processes. A process, in turn, achieves some specific outcome (e.g., the living individual) from a set of anteceding conditions (e.g., forms of energy) in one or more transformations (e.g., according to the prescriptive instructions in the gene). Where there is minimal interference (e.g., from hard radiation) which changes the "program" itself that program will unfailingly compute and re-compute identical individuals (e.g., twins, or clones).

The technical term for the "program" that describes and prescribes any process is "algorithm." Properly speaking algorithms are abstractions that are valid only in the formal world of logic and mathematics and are no more to be confused with the actual process they describe/prescribe than a map is to be confused with the real terrain it represents. An algorithm describes what happens in the process of arriving at some given outcome, and, at the same time, the algorithm prescribes what must be done in order to attain this outcome. To accomplish the latter the prescriptive directions of the algorithm must be such as to completely determine the actions of the "doer" or executor so that he does neither more nor less than is required and only in the permissible order(s).

As we can see algorithms are very specific, i.e., they must not leave room for chance or choice on the part of the executor, nor may they be ambiguous or equivoval (allow two or more interpretations). If an algorithm has been properly prepared, it may be executed by anyone possessing the requisite capabilities. It is also general, because it can be applied to attaining the sought after outcome in each and every one of a defined set of situations. Lastly, algorithms guarantee results. When properly applied and executed, the sought after outcome is invariably obtained.

The importance of these three properties of specificity, generality and resultivity is undoubtedly self-evident and needs no lengthy discussion. As we have seen, an algorithm can be likened to a map, a blueprint, an x-ray and (loosely) to a plan of operation(s). We now see that a properly constructed

algorithm will carry an inherent guarantee of being an accurate representation of a real process due to its possession of these properties (specificity, generality and resultivity). These properties are at once the promise and the test of a proper algorithm[1/].

The Description of Human Activity

The accurate and reliable description of human occupational and learning activity has been a problem of long standing. Job analysis was explained as follows in one early textbook.

> "Job analysis involves dissecting a job both from the standpoint of the work and from the standpoint of the worker. It leads to a detailed job specification or occupational description which may be used for improving working conditions, promoting health and safety, perfecting methods of training, and supplementing employment procedure." (Burtt, 1942, p. 532)

In later years the desirability of more precise and detailed descriptions of job activity led to task analysis, i.e., of the major activities repeatedly performed by a given job or duty incumbent. The applications expanded beyond those envisioned by Burtt such as, matching the worker to (selecting for) the job, to include performance assessment, equipment design for optimal man-machine interaction, prediction of training requirements, occupational engineering, and so forth. In short, analysis and specification of relevant activity is seen to be the key to dealing effectively and efficiently with any matter involving human performance of any sort and in any way. As pointed out in the preceding section, some form of representation is necessary in order to deal effectively with any situation.

Whether at the relatively gross level of job analysis or at the fine-grained level of task analysis the source of information and the nature of the activity description have been problematical. For example, Burtt (1942) suggests that interviews of incumbents or observing their job performance are the ways to obtain the data for the descriptions. Refinements of this approach include questionnaires and recordings of observed activity, but do not alter the hearsay and intuitive and judgmental character of the methodology (see, e.g., Fine, 1955a, b, 1962, 1963, 1965; McCormick, Cunningham and Gordon, 1967; McCormick, 1970; Prien and Ronan, 1971). It will be recognized that incumbents may not be performing their job properly, that they are often unable to describe how they perform some task or other (e.g., tying some complex knot) and that many decision processes are cognitive, covert and, therefore, not amenable to outside observation. These latter capabilities are often called "soft skills." Therefore, emerging job or task descriptions must of necessity resemble the mediaeval maps drawn from accounts of travelers augmented by liberal imagination. The accuracy of these representations is hardly ever tested and verified, and normally accepted on faith.

So long as the foundations are not firm, any schemes erected on these foundations (e.g., performance tests, training plans and outlines) will have an arbitrary and vulnerable status. The issue was most clearly put in the opinion of an English judge in India, rendered many years ago in a case involving intricate statistical data, which held that while the (British) government is very fond of amassing statistics, of combining data and reaching intricate conclusions, one must remember that the original information comes from the lowly village official "who puts down what he damn well pleases." One example of elaborate and sophisticated structures erected on the problematical foundations of traditional task descriptions is a taxonomy of human performance[2/]. The validity of such a system of classification will be only as dependable as the validity of the data underlying it.

An Alternate Approach to Activity Description[3/]

At the outset we began to explain the concept of the algorithm, its powerful properties and how these properties provide the key to an accurate and verifiable representation of dynamic processes. It may be seen that most, though not all[4/] task performance by human beings is of that type. The algorithm of a task provides its description, prescription and specification. The overwhelming majority of of industrial and military tasks can be specified in algorithmic terms. Before showing how this may be done, however, some further explanation must be made.

1/ A more comprehensive explanation of algorithms can be found in Trakhtenbrot (1963) and a rigorous mathematical development in Markov (1954).

2/ See, for instance, Wheaton (1968), Farina (1969), Theologus (1969), Chambers (1969), Theologus, Romashko and Fleishman (1970), Miller (1971a, b), Farina and Wheaton (1971), Teichner and Whitehead (1971), Levine and Teichner (1971), Theologus and Fleishman (1971), Levine, Romashko and Fleishman (1971).

3/ A fuller treatment of material in this section can be found in Landa (1974).

4/ For a discussion of semi-algorithmic, semi-heuristic and heuristic tasks see Landa (1976, Ch. 5).

We pointed out that an algorithm is properly valid only with respect to logical and mathematical problems. This is due to the requirement that there must be no room left for chance and choice. In the real world, unlike the formal world, all uncertainty about future events and/or conditions to be encountered by the task executor (performing individual) cannot be excluded so that some degree of chance and, hence, choice must of necessity enter. This violates the important requirements for absolute specificity and univocality in the prescriptive directions. In other words, because he cannot entirely foresee what will happen or what conditions will be encountered, the author -- the creator of the algorithm -- cannot provide all of the information required to completely determine what is to be done.

The difficulty can be overcome for practical purposes. Human beings have the unique capability of supplying missing information so that they can potentially follow directions that do not provide all, but only most of the information required to determine what is to be done. Their ability to follow such incomplete prescriptions increases the more the range of choice left to them (the requirement for independent judgment -- action not determined by given directions) decreases. When the range of choice has been reduced to triviality, the activity of the task executor is virtually completely determined and there is virtual certainty that the correct, missing information will be furnished. For example, rather than saying "go to a fire exit" it can be specified "go through the red steel door at the end of this hallway..." So long as the behavior (actions) of the task executor does, in fact, correspond entirely with the intent of the prescriptive directions uncertainty has been neutralized, and the above mentioned difficulty has been eliminated. Properly speaking the set of prescriptive directions in such a case does not constitute an algorithm but rather a quasi-algorithm. It differs from an algorithm in not absolutely and unconditionally possessing the properties of specificity, generality and resultivity, but only with an exceedingly high probability (e.g., .999...). For practical purposes the distinction vanishes.

Quasi-algorithms are extremely close approximations to (formal) algorithms, but they are not entirely identical. In the above example about the fire exit, it will be self-evident that the behavior of non-English speaking persons will not be determined by the given directions. The author and the recipient of the directions must share the same language and the same alphabet. Thus quasi-algorithms (not formulated in the universal language and symbols of mathematics) are valid only relative to a defined population, the English speaking population in our example. There is, also, a further way in which the validity of a formulated quasi-algorithm is relative to a defined population.

Assume a prescriptive direction within an algorithm which reads "integrate sin t with respect to t from 0 to $\pi/2$." If the direction for this operation is addressed to a population with mathematical sophistication (mathematicians, engineers), it can be presumed that the direction will be elementary. That is to say that virtually any individual from this sophisticated population will know exactly what to do in following the direction and will be able to execute the given instruction. On the other hand, if the addressed person were a soldier with no more than 12 years of education and little mathematical training, it is unlikely that he could comprehend and execute the given direction. For this latter person the instruction would have to be broken down into finer detail (into a more fine-grained algorithmic segment) in which each given direction is elementary for the addressed individual. Elementarity of prescriptive directions (for operations to be executed), then, is relative to a given addressed person, or as a practical compromise to a defined population.

The example of a mathematical calculation leads to another notable point. The execution of such a calculation takes place "in the head" and is not directly observable. In cognitive activity (e.g., evaluating a situation, reflecting about possible courses of action, reaching a decision -- the so called "soft skills") generally the process is covert. However, the results of that process, including intermediate results, will be or can be made overt. In principle the process of correct reasoning (about some though not all problems) can be algorithmically or quasi-algorithmically delineated, and the consequences of improper execution of component steps for overtly displayed results can be inferred. In turn, the place and character of the mistake in reasoning can then be deduced from the fault in the displayed result. This precise diagnostic capability confers on the quasi-algorithm its x-ray like character. As with no other extant technique the internal structure of "soft skill" reasoning processes can be revealed so that they may be precisely delineated, checked and guided. Also, it should be noted that the quasi-algorithmic specification of cognitive and, therefore, covert tasks is far more precise and defensible than the vague, intuitive statements in traditional job/task analytic approaches. Simon (1976) even demonstrates the uses of computer simulations (i.e., formal algorithms rather than quasi-algorithms) in identifying basic abilities underlying intelligent performance of complex tasks.

A final point to which attention must be drawn is the possibility of multiple, equivalent quasi-algorithms, since there is often "more than one way to skin a cat." In principle, the number of such alternate ways of accomplishing identical ends could be quite large. As we shall see later in this report, this is not truly the case in many industrial and especially in military contexts in which specific ways of doing things are usually prescribed. That significant alternate versions can be reduced to a very few for practical purposes also follows from these considerations. First, absurd variants can be ignored for practical purposes (e.g., one does not change a tire on a car while standing on one's head). Second, trivial differences can be ignored (e.g., data may be entered into the FADAC keyboard either righthanded or lefthanded). Third, many alternative versions will involve nothing more than a rearrangement of some sequences of activity (e.g., in changing a tire: fastening lug-nuts immediately versus first starting each nut and then tightening the nuts in sequence).

Specifying Tasks in Quasi-Algorithmic Form

Up to this point it has been suggested that traditional approaches to describing much of "practical" human task behavior are found wanting, because of their imprecision and unreliability. At the same time it was hinted that a solid foundation to the description, prescription or specification of task-executing behavior could be provided by an algorithmic, or rather a quasi-algorithmic approach. The latter approach will merit consideration over traditional approaches if and only if the accuracy and sufficiency of the quasi-algorithm in describing/prescribing the path to successful task accomplishment can be objectively demonstrated, because traditional approaches have been found wanting in this respect.

It was said that a (quasi-)algorithm at once describes what happens in arriving at some set of outcomes (task objectives, results) and prescribes what must be done (by anyone) in order to arrive at these outcomes. Not only can anyone (from the applicable population) follow the established prescriptions, but (when properly applied) these persons may do so for any task in the defined set. For example, the algorithm for dividing one real number by another real number is applicable not only to dividing 243 by 3, or to dividing 3.1416 by 2.17, but to the division of any real number by another real number. These are the properties of specificity and generality. The third property, resultivity, guarantees (in the case of quasi-algorithms practically guarantees) that the sought after outcome will be (more or less) inevitably obtained.

The test or the verification of a quasi-algorithm -- the proof of its validity and reliability -- follows directly from its properties. If every individual in a sample of people drawn from the applicable population performs a given type of task according to its prescriptive directions (perhaps with different, but applicable data sets) and everyone uniformly achieves the specified outcome, both, reliability and validity are demonstrated. In principle, the experimental proof is exceedingly simple and straight forward, and practice, as will be seen later, does not fall far short of the ideal. While the reliability of the developed quasi-algorithmic task specification (the consistency with which successful task execution will occur) can be estimated via distribution free statistical tests (such as, run tests), they will not really be necessary if such task specifications have been meticulously prepared.

A practical procedure incorporating this verification methodology takes the following form. A draft of a task specification is prepared. Then an expert in the subject-matter area within which the task falls is recruited to participate in the test procedure. The prescriptive directions in the draft task specification are read off to the expert step-by-step (operation-by-operation). The expert must agree to follow the given directions exactly. He may ask for clarification of any component direction from the "author" or person administering the draft task specification. Any such request is honored, noted, and a suitable revision in the prescriptive direction is made. So long as the intent of the given prescriptive direction is clear to the participating expert he must at once follow it to the letter and seek to escape from it. In short, he must try to demonstrate that the prescriptive direction does not totally control his action(s) but allows some options. If he can escape from the given direction(s), a note is again taken and a revision must be made. If he cannot escape and is forced to complete the task successfully, this constitutes convincing evidence that the established set of prescriptive directions -- the quasi-algorithmic task specification -- has, in fact, totally determined (controlled) the expert's task execution.

The practical procedure is one that must be repeated (iterated) with several successive experts. Normally the initial iteration(s) will reveal flaws, and these must be progressively corrected. Since the flaws are being progressively eliminated, a stage is reached in which the participant expert's task execution is completely controlled by the prescriptive directions, and this will tend to be equally true (though not absolutely guaranteed) for succeeding experts. While "dottings of i's and crossings of t's" may still occur, these trivia no longer significantly affect the course of task execution. In practice the author (possibly in consultation with the experts) reaches a conviction that additional administrations will not reveal any more invalidating flaws and terminates the verification procedure; this conviction can be statistically evaluated and confirmed, as explained above.

An additional stage of development and verification will be required where the intended use of the task specification is instructional. This is due to inevitable differences in the elementarity of prescriptive directions for expert instructors and trainees. While the previously outlined procedure with expert participants guarantees the basic validity of the task specification, it does not guarantee that each of the component directions will be elementary for different (e.g., student) populations. An appropriate level of elementarity must be developed by breaking down some prescriptive directions (e.g., "read the value on the scale") into a more fine-grained algorithmic segment (e.g., how to read that scale). Then the adequacy of the break-down -- of the elementarity -- must be tested with a sample of students in a manner analogous to that outlined for the experts.

TRIAL DEVELOPMENT AND TEST

In order to assess the practical feasibilities of the possibilities outlined in the preceding segment of this report an exploratory trial development and verification of some quasi-algorithmic task specifications was undertaken. The context chosen for this purpose was the Fire Direction Center (FDC) of some hypothetical Field Artillery (FA) Battalion equipped with 155 mm self propelled (SP) howitzers. Since it would be impossible within the scope of this exploratory project to deal with all activities of all members of the FDC, a plausible sample of certain standard FDC mission activities was selected. The activities included the individual tasks associated with the preparation of a surveyed firing chart, and those associated with a type of routine fire mission described in FM 6-40 (Ch. 18). In the latter the FDC receives a call for fire (CFF) from a Forward Observer (FO), a single piece fires several adjust rounds of high explosive (HE) ammunition with Fuze Quick (impact detonation), and this is followed by a fire for effect (FFE) phase in which an entire designated Battery (or Batteries) fires a specified number of HE rounds possibly detonated by time (Ti) or proximity (VT) fuzes.

Again it was not possible to deal with all tasks of all members of a standard FDC team. Therefore, only those tasks performed by normally active (rather than passive, supervising) FDC team members were selected and only those having some significant content. For example, the activities of the Radio Telephone Operator (RTO) were excluded, because he is confined to parroting the message traffic. Conversely, the decision processes of the Fire Direction Officer (FDO) were considered too complex for consideration at this exploratory stage. Thus, approximately, the tasks considered are those of the enlisted personnel (MOS 13E 10/20/30) that are regarded to be of sufficient significance to merit instruction in the U. S. Army Field Artillery School (USAFAS). It must be remembered that the intent of the project was an exploratory trial rather than an exhaustive development.

Development of Draft Task Specifications

As a first step pertinent documents were sought and obtained. They include AR 611-201, ARTEP 6-365 (Dec 1976), FM 6-40, FM 6-40-5, and a set of self-study guides prepared at the USAFAS, Ft. Sill, OK. It was chiefly these documents which were studied so as to obtain a preliminary grasp of the relevant situations and tasks. The realism of these situations was checked against an actual Army Training Test for a FA Battalion (ATT 6-155, 3rd Armored Division Artillery, 1975). A sketch plot of events and their order in the routine fire mission were drawn up and obscure points noted. This plot and the questions were then reviewed with some knowledgable persons[5/]. Appropriate corrections were made. Gradually the set of individual tasks comprising the routine fire mission and their interrelationships began to emerge. Also, very general and provisional notions as to how these tasks should be performed began to be developed. They were again reviewed with the expert consultants.

At this stage some very brief and preliminary attempts were made to perform the identified individual tasks. These attempts were principally for the purpose of identifying relevant questions. These questions were then taken to USAFAS at Ft. Sill and reviewed exhaustively with an expert[6/] by one of the present authors (EHK). Upon his return he taught back the procedures he had learned to the other author (FFK). Since this instruction had already taken on an algorithmic cast, it proved to be highly effective and efficient. In other words, both authors felt moderately confident that they now "knew how" and could perform the tasks in question with the support of the reference documentation.

As a next step each of the authors independently developed a rough draft specification for each identified task. It must be stressed that these rough-drafts were more in the nature of procedural notes than meeting the requirements of clarity, univocality, specificity, etc. of a proper quasi-algorithm. However, these rough drafts were sufficiently clear for mutual administration; A read off his prescriptive directions to B, took notes of ambiguities, failures, etc. and then B reveresed his role with respect to A. On the basis of this experience and of the notes made it was possible to draw up a set of draft task specifications in proper form, i.e., with extreme restrictions on choice, coverage of all possible conditions, elimination of ambiguities and equivocalities, and so forth. The level of elementarity at which the prescriptions were drawn up was presumed to be appropriate for an eventual expert test population.

At this stage, it may be clear, the draft task specifications had gone through possibly two cycles of revision (in the mutual administration). Next an expert was recruited[7/] and talked through the prescriptive directions comprising each and every draft task specification. Surprisingly only a few minor

---

5/ Invaluable help in terms of advice and the loan of equipment was provided by LTC Robert E. Klein, CPT Stephen M. Lutz and SGM Charles H. Fagg of the U. S. Army ROTC Unit of La Salle College in Philadelphia, PA.

6/ SFC Russell Evans, Fire Direction Division, Gunnery Department, USAFAS.

7/ CPT S. M. Lutz of the La Salle College Army ROTC Unit.

remaining mistakes were identified and corrected. Hence, the draft task specifications were thought to be ready for final test and verification cycles.

Economics of Development

An attempt had been made throughout to keep an accounting of the time spent in developing each draft task specification. A starting and stopping time was recorded on every draft document to make this possible. Hence elapsed time could be recovered. This account of time spent in the actual drafting and revising of task specifications is shown in Table 1.

Table 1

Development Times for Draft Task Specifications
(In Minutes)

Task and Version	First Draft	Revision	1st Draft Plus Revision
010	60	60	120
020	240	70	310
030	180	60	240
040	210	180	390
051	90	-	90
052	30	30	60
053	60	-	60
060	30	-	30
070	20	-	20
080	10	-	10
090	60	45	105
101	45	-	45
102	30	-	30
111	30	-	30
120	5	-	5
130	15	-	15
140	5	-	5
150	30	-	30
160	30	-	30
170	10	-	10
180	10	-	10
190	5	-	5
Total Minutes	1205	445	1650
Total Hours	20 hrs 05 m	7 hrs 25 m	27 hrs 30 m

It should be noted, first of all, that actual drafting of the quasi-algorithmic task specifications could not begin until a given task had been identified (within the overall FDC mission) and mastered resonably well. The time for this background preparation was too scattered, uncertain, could not be summarized and is not included in Table 1. Also, the account is only for a single author's time. The time for the previously mentioned duplicate development was not included, because (a) these versions were extremely rough and preliminary, and (b) the accounting should reflect the economics of a normal, single (not duplicate) development. Finally, the times shown are those for formulating and handwriting a draft; the time needed to convert to typed copy is not included.

It will be seen in Table 1 that a grand total of some 27½ hours was devoted to arriving at revised "semi-final" task specifications. Of these 20 hours and 5 minutes were devoted to preparing the original drafts and 7 hours and 25 minutes to making revisions. Only six out of 22 distinct task specifications required any revision. The greatest amount of time for preparation and for revision was required in the relatively lengthy, complex and perhaps more cognitively demanding tasks related to preparing a surveyed firing chart. All of these draft specifications had to be revised. Of the remaining 18 only 2 needed revision.

Revisions, as that word is used here, refer only to basic changes in substantive content and organization (structure) of the task specifications. Hence they do not reflect corrections needed, for example, because of a mistake in the numbering of some prescriptive direction (see explanation of Index Numbers, p. 12). Such mistakes entail complex consequences, because subsequent Index Numbers inevitably also become incorrect, subsequent references to specific Index Numbers become misleading, and so forth. Correction of such mistakes tends to be time consuming, but such efforts are also not reflected in Table 1.

Verification Procedures and Results

The revised draft task specifications were taken to the USAFAS at Ft. Sill, OK and subjected to the test/verification cycles described in principle earlier (see, Specifying Tasks in Quasi Algorithmic Form). Through prior arrangements with the Fire Direction Division of the Gunnery Department, five members of its senior instructional staff[8] were made available as expert subjects for these purposes. Each of these senior instructors was intimately familiar with each task in the set, had himself performed it innumerable times, and had also taught it to others. Administrator of task specifications and expert subject (one per session) met in a quiet room with all requisite implements on hand. The following explanation was read to, and simultaneously by each participant expert.

PROCEDURE FOR CHECKING OUT TASK SPECIFICATIONS

The purpose of this exercise is to test the accuracy and completeness of certain Task Specifications. IT IS IN NO WAY A TEST OF YOUR CAPABILITIES! The tasks that are specified or described are tasks which you know how to do very well. Because you are an expert, we are asking for your help in this research effort which is being conducted for the Army.

Together we will test each of these Task Specifications in the following way:

1. I will read a set of precise directions as to what you or anyone else must do to accomplish each task. I will read the directions one at a time. You may want to read along with me in your copy. However, DO NOT READ AHEAD OR ANTICIPATE ACTIONS.

2. After a direction is read you may ask for clarification. For example, you may want to have the meaning of some word or phrase explained. The object is to have you UNDERSTAND PRECISELY WHAT THE DIRECTIONS TELL YOU TO DO. Don't do anything until you have it clear in your mind what you are to do.

3. Next, you must do EXACTLY what you have been told to do, BUT if there is a way of defeating the given direction while following it to the letter -- A WAY OF "DOING IT WRONG" THAT IS PERMITTED BY THE WAY THE DIRECTION IS SET UP -- you must try to find it. For example, if the direction tells you "find the next grid line" (but does not say next after which other one, nor in what direction) try to pick a wrong one. Or again, if the direction tells you to "align graduation with pinhole" (but not which particular pinhole), try to make trouble. At the same time, let's not quibble over things that are perfectly clear in context.

Please note that each direction that is listed is identified by a unique number. If there is no number in the "Branch to Index No." column, you go to the next higher number. In other words, you go to the direction listed immediately below the current one. Otherwise you go to the direction with the specified Index No.

Let me explain a few words that you will find and the standard meaning we have given them. First, there is the word STORE. It means that information is to be held for later use. At this time this means that the information may be held in memory, jotted down on a scratch pad, entered on DA Form 4504, or what have you. STORE does not care how it is done so long as the complete and correct information can be readily retrieved. Of course, RETRIEVE means simply that previously stored information is brought back, ready for use.

On occasion we may use a phrase "reference tick mark". It means the tick mark that represents a particular point (perhaps a battery) with reference to which some measurement or calculation is being made.

Whenever something "goes wrong" I will have to stop and take notes. Please be patient and wait. Also, after each task is completed I will ask some questions.

8/ SSG S. L. Davis, SFC R. Evans, SFC P. Ives, SFC J. L. McFadden, and GYSGT L. E. Nowak (USMC).

The administrator then proceeded to read off successively the prescriptive directions in the various tasks. Normally the expert could easily envision the effect of each given direction. When there was any doubt, the step(s) was overtly performed using the available equipment. In each administration all conditions and branches were entered. That is, as soon as a branch entered under the assumption that condition A applied was completed, administrator and expert recycled to the beginning of the branch and assumed condition B, and so forth. Not only could the experts test each branch, but they could also judge whether every (practically) possible condition had been covered. Upon conclusion of each task and of all tasks the participant expert was asked for general judgments about the adequacy of the task specifications and for elaborative comments. The time required to complete this procedure for the set of 22 task specifications ranged from two to two and one half hours.

In effect, none of the participant experts was able to escape from the prescriptive directions that had been prepared. While some changes were suggested, these changes did not arise from a lack of validity of the task specifications.

Some changes were necessitated by idiosyncratic disagreements among the experts. For example, should identification of a chart grid-square be maintained by inserting a pin in it, making a pencil mark within it, or by pointing to it. Some changes were due to recent FA doctrinal changes. For example, the FDC team member known as the Computer announces the number of rounds to be fired and the fuze type to his Battery not when the fire mission is first announced (Task 13), but only on first giving Quadrant Elevation (Task 19). Some changes only endow the task specification with a greater range of applicability. For example, in establishing a Vertical Interval (VI) via a vertical shift an observer's location as well as a designated known point may be used as the reference location for the shift. Finally, a good many changes were of a refining, "polishing" type having scarcely any practical significance. For example, how to number grid lines on a chart with minimal or no margins.

Changes of the above types that suggested themselves during the verification procedure have been incorporated into the final versions of the task specifications which follow in the next segment.

TASKS AND THEIR SPECIFICATIONS

Tasks for which quasi-algorithmic specifications were developed are listed by title in Table 2 below. A fuller explanation of the Index Numbers follows (p. 12), but for the moment it must be understood that the first two digits of the Index Number constitute the Task Number.

Table 2

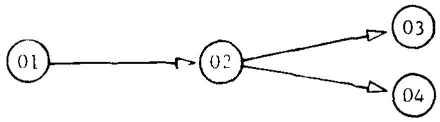
Index No.	through Index No.	Individual Task Specification
010000	010300	Numbering Blank Firing Chart
020000	020470	Plotting Critical and Non-Critical Points
030000	030550	Constructing Azimuth Indexes
040000	040600	Constructing Deflection Indexes
051000	051110	Plot Target - Grid Coordinates Method
052000	052100	Polar Plot of Target
053000	053140	Plot Target by Shift from Known Point
060000	060090	Determine Range with RDP
070000	070050	Determine Deflection with RDP
080000	080060	Giving Rg and Df to Battery Computer(s)
090000	090130	Determine Angle T
101000	101130	Determine Vertical Interval from Map
102000	102120	Determine VI via Vertical Shift
111000	111170	Compute Site
120000	120050	Announcing Site
130000	130060	Record Fire Order and Announce Fire Mission
140000	140070	Re-Announcing Number of Rounds and Fuze to Battery
150000	150080	Compute and Announce Deflection to Battery
161000	161150	Compute Quadrant Elevation
170000	170070	Derive Time or Fuze Setting (FS)
180000	180050	Announce FFE Data to Battery
190000	190060	Announce Quadrant Elevation

Tasks 01, 02, 03, and 04 represent the preparation of a surveyed firing chart by a chart operator (HCO or VCO) to whom the requisite data are given (for example, a student at the USAFAS). The approximate context for this set of tasks derives from ARTEP 6-365 (Dec 76) on page 3-46, "Task (1)." A summary explanation of the purposes of firing charts and a general description of their preparation may be found in FM 6-40 (C1) pp. 16-11 to 16-14.

In preparing a Surveyed Firing Chart the first task to be accomplished is the numbering of the blank chart grid. This will be followed by the plotting of various critical and non-critical points, such as, battery locations, observer locations, registration points, etc. Next, the required azimuth (Az) indexes would normally be constructed, and then the appropriate deflection (Df) indexes. The simple sequence of these tasks

01 → 02 → 03 → 04

is mainly dictated by the progressive generation of more or less essential information on the Chart. Thus points cannot be plotted until grid lines have been numbered, and Az and Df indexes cannot be constructed until their points of reference (tick-marks) have been plotted. In principle, there is no true obstacle (lack of pre-requisite information) to constructing Df indexes before Az indexes so that the order of their possible performance is as follows.



It should be noted that Tasks 01 through 04 represent the activities of a single individual rather than a team effort. While the individual (the Chart Operator) must have certain items of information (e.g., Az of lay), it can be easily presumed that this information was developed "long ago" -- was written down -- and is readily available to him. His ability to proceed is not contingent on the information being concurrently developed by another FDC team member. Thus the specification of the permissible order(s) of task execution is a relatively simple matter.

In general the task specifications for Tasks 01 - 04 assume that a full 6400 ₥ chart is being prepared. In the case of Task 01 a minor restriction in applicability exists. That is, where there is a grid zone convergence a sudden discontinuity in the grid line numerical sequence will occur rather than these numbers constituting a simple ones-incremental (or decremental) series. Under these conditions the Task Specification will not produce the sought after outcome. However, grid zone convergence is an extremely rare (and, therefore, practically negligible) condition.

In the case of Task 03 it is possible to construct successive supplemental Az indexes around the clock by constructing each successive index from the immediately prior one. Because this method will accumulate excessive degrees of error, it is frowned upon. While this argument does apply, as well, to Task 04, the Df indexes are constructed in the around-the-clock fashion. This seeming contradiction is due to the fact that Df indexes tend to be constructed only for a fairly restricted arc (principal direction or zone of fire), and -- Tasks 03 and 04 being quite similar -- the development of task specifications for both methods could be essayed.

For each of Tasks 01 - 04 the necessary implements are assumed to be on hand. That means: a blank firing chart has been taped down on a suitable surface, a 6H pencil has been sharpened to a wedge point, and a 4H pencil, red/blue pencil, green and orange pencils have each been sharpened to conical points, and that pins and erasers are also available. Also on hand are all of the standard "tools of the trade" including the Range Deflection Protractor (RDP), Coordinate Scale, etc.

Unlike Tasks 01 - 04, Tasks 05 - 19 represent the activities of a Fire Direction Center (FDC) team, i.e., the interaction of several individuals. The approximate context for this set of tasks is the simple fire mission illustrated in FM 6-40 (C1) pp. 18-13 through 18-16. Constraints of time precluded the inclusion of all activities of all participants in this type of fire mission. Also, a comprehensive task specification development falls clearly outside the scope of an exploratory effort such as this one. While it was not possible to consider, in detail, the activities of a Forward Observer (FO), Fire Direction Officer (FDO), Chief or Assistant Chief Fire Direction Computer and of the Radio Telephone Operator (RTO), the tasks of the principal actors are all specified. By the latter are meant the Horizontal Control Operator (HCO), the Vertical Control Operator (VCO) and each of the Battery Computers whose activities normallv parallel each other.

In this mission context the FO enters only in providing an information input: (1) the call for fire (CFF), (2) corrections of range (Rg), deflection (Df), etc., and (3) specifying when Fire for Effect (FFE), as opposed to adjusting rounds, is to commence. The FDO decides whether to accept, modify or reject the CFF and issues the Fire Order (comprising 10 elements of information shown below). If the Fire

FIRE ORDER STANDARDS	
ELEMENT	CURRENT STANDARD
UNIT TO FIRE	
ADJUSTING ELEMENT/METHOD OF FIRE OF ADJUSTING ELEMENT	
BASIS FOR CORRECTIONS	
DISTRIBUTION	
PROJECTILE	
AMMUNITION LOT AND CHARGE	
FUZE	
NUMBER OF ROUNDS	
RANGE SPREAD, LATERAL SPREAD, ZONE FIRE, OR SWEEP FIRE	
TIME OF OPENING FIRE	

Order has been standardized, he need scarcely enter at all and can allow the mission to proceed on the basis of pre-established information. Thus for present purposes the FDO's role is "*minor*," but also too highly complex to be dealt with. By contrast the RTO is frequently involved in the mission (i.e., the coordinated activities of the FDC team), but, since he merely parrots the message traffic, his activities are trivial.

Triviality of the activity also led to the making of an underlying general assumption for the entire set of individual tasks, i.e., that FADAC was not available. Further, it was assumed that Graphical Firing Tables (GFT) rather than printed Tabular Firing Tables (TFT) would be used. The corrected settings for the GFT (elevation and time) are assumed to have been previously established. Also, it is assumed that a surveyed firing chart has been prepared (Tasks 01 - 04).

The overall mission, then, is quite representative of an uncomplicated reality. It is a "textbook" mission of the type to which new trainees tend to be introduced. Most of the essential component tasks were analyzed and are specified, but not all. For example, no specification was developed for the announcement of Angle T, which is not an inevitable event. Neither were specifications developed for those activities that tend to occur after the FFE phase including the proper completion of DA Form 4504 (Record of Fire).

Subject to these qualifications the normal course of events in this *kind of fire mission is as* follows. The FO transmits a Call for Fire (CFF) containing these six elements of information: (1) Self-

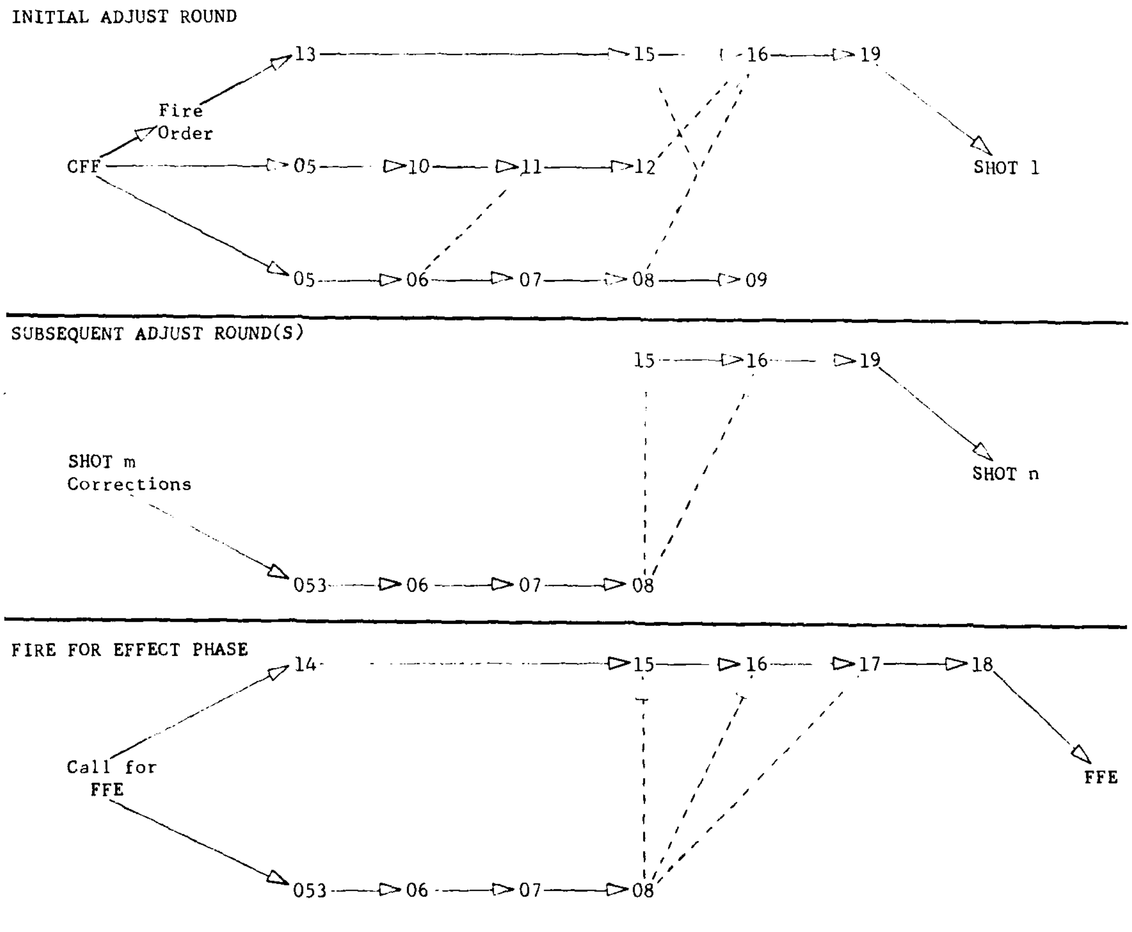


Figure 1. Task Plot for Routine HE Fire Mission

Identification, (2) Warning Order (i.e., type of mission), (3) Target Location, (4) Target Description, (5) Method of Engagement, and (6) Authentication. The very first element of the CFF triggers the Battery Computers to record the incoming information (plus such changes to Fire Order standards as the FDO may issue) and to announce the Fire Mission (Task 13). The third element of the CFF triggers both Chart Operators (HCO and VCO) to engage in the plotting of the target on their charts (Task 05 in any of 3 versions). Next the HCO determines the range (Task 06) and then deflection (Task 07), and then he announces both to the Battery Computer(s) (Task 08). Thereafter the HCO will proceed with the determination of Angle T (the angle formed at the target by the Observer-Target line and the Gun-Target line); this is Task 09. The VCO meanwhile will be determining the Vertical Interval (Task 10 in either of 2 versions), then compute Site (Task 11) and then announce Site to Battery Computers (Task 12). Df (from HCO) enables the Battery Computer to compute and announce the corrected Df (Task 15). Rg (from HCO) and Site (from VCO) allow him to compute Quadrant Elevation or QE (Task 16). The preparation for the first round in the Adjust Fire Phase terminates with the Computer's announcement of QE which causes the firing unit to fire the first shot.

In turn, observation of this shot leads the FO to transmit the necessary corrections (e.g., to Rg, to Df) which are noted. For the next and all subsequent adjust rounds the HCO, the VCO and the Computer(s) repeat these respective activities. The HCO will re-plot the target (Task 05 version 3), redetermine Rg (Task 06) and Df (Task 07), and then announce them (Task 08). The VCO will be duplicating the HCO's activities except for the overt announcement. The Computer(s) will compute and announce the corrected Df (Task 15), then compute QE (Task 16) and again announce QE (Task 19). The announcement of QE again causes a round to be fired by the firing unit(s).

When the FO transmits the FFE call the HCO and VCO repeat the same activities as during the Adjust Fire phase. However, the Computer(s) then reminds the Battery of the number of rounds to be fired and the fuze type per the Fire Order (Task 14) and then performs Tasks 15 and 16 as before. Then it is necessary to derive Time or Fuze Setting (Task 17), and then all the reqisite FFE information is announced (Task 18).

A plot suggestive of the order of task execution in the representative, routine fire mission (per FM 6-40) is shown in Figure 1. To simplify the representation redundant activity (e.g., of VCO and HCO or of multiple Battery Computers) has been omitted. Tasks are plotted in their approximate phase relationship with time proceeding from left to right. Clearly, a discontinuity occurs each time a round is fired. Where the execution of an individual team member's task is contingent on an information input from an outside source (i.e., information that he does not receive in parallel or himself generates) this has been indicated by dashed lines.

Reading Task Specifications

1. Headings. The headings which precede each task specification are not a formal part of it. These headings merely provide some orientation for the reader as does the title of a book or a chapter heading. Undoubtedly, disagreements with the headings are possible, idiosyncratic changes might be made, but this would not affect the validity of the body of the task specification; as mentioned before, the label on the box is only suggestive of the contents and not a part of it

The headings suggest, first of all, the general mission context. This corresponds roughly to the use of "TASK" in an ARTEP and represents some outcome to be achieved (usually) by coordinated activity of a team or unit. Next it is suggested which team member (i.e., duty position) is likely normally to execute the task. Last, a task title is given to provide a convenient verbal label for the individual task.

2. Index Numbers. Merely to demonstrate the possibility of such a code, which would be absolutely essential for storing and retrieving this sort of information in a computer a provisional and arbitrary scheme was devised. The scheme works readily in the present circumstances, but for any operational purposes it is likely to need expansion. If a new and more capacitous code were to be devised, the present could be mapped into or onto the new one. In other words, the job of renumbering is easily accomplished.

The present Index Numbers are established in accordance with this code. The first two digits designate the individual task. For example, "Numbering a Blank Firing Chart" has the code 01 in the first two positions, i.e., it is Task 01. The assignment of a number is completely arbitrary, but it must be a unique assignment.

The digit in the third position represents the version of the task (i.e., equivalent quasi-algorithms leading to the same outcomes). If there are thought to be no known or permitted varients (alternate ways of doing the same thing), the code is 0. Clearly, it is questionable whether particularly any of the set of Tasks 05 - 19 could be legitimately so coded, since most of them could be accomplished through FADAC. The pro's and con's need not be argued, since the object, at present, is to explore and demonstrate feasibilities and not to develop some definitive design documentation.

Digits four and five designate the particular operation (action or decision within a given task and version. Assignment of these numbers occurred as their associated operations were written, but they do not necessarily designate the order(s) in which these operations must be executed. Again, the assignment of these numbers is arbitrary, but unique.

The sixth digit represents the version of an operation. If there are no known or permitted variants the code is 0. Otherwise codes 1 - 9 are assigned to distinguish the variants.

An Index Number according to the above code uniquely designates any elementary prescriptive direction, e.g., a version of an operation within a version of a task within a set of tasks. Hence, all items of prescriptive information may be stored, retrieved, addressed and ordered simply in terms of their *Index Numbers*.

Because a six-digit code is somewhat difficult to read (for human beings) a simplifying convention has been followed in the printed Task Specifications. The full, six-digit Index Number appears at the beginning of any task or task version. *Thereafter, on the remainder* of that page, those codes that do not change have not been printed (but must be envisioned to exist) so as to simplify reading and reader orientation. Only the fourth and/or fifth digits (which *designate the corresponding* operation) are printed. This is also true for Index Numbers designated in the "Branch to" column. Unless a branch outside the given task and version is intended only digits four and/or five are shown (and the rest are understood. The full six-digit code is not printed again until there is a page change (thereby uniquely identifying the page) and/or when the end of the particular Task Specification (TS) has been reached.

3. Operations. The middle column provides the prescriptive directions as to the actions to be taken or the decision to be reached. Actions to be taken may be either overt (e.g., "select a pin") or covert (e.g., "divide by five"). The obligation of the reader is to "get it completely clear in his mind" and in every detail what he is being directed to do. Decisions are represented in binary form. When there are multiple branches from a single point, this is handled through a succession of binary decisions.

4. Reading in Ordered Sequence. Begin reading any Task Specification at its beginning, that is with the operation whose Index Number is coded 00 in the fourth and fifth digits. Then proceed to the very next *operation* (No. 1). If no Index No. appears in the "Branch to" column next to that operation, proceed to the very next operation below; otherwise, proceed to the Index No. shown in the "Branch to" column, *read it and go on from there. So* long as there are no Index Numbers in the "Branch to" column always proceed to read the next operation below.

If any next operation involves a decision, the "Branch to" column will always contain two Index Numbers. The decision to be made is between the *conditions represented* by "YES" and by "NO." If "YES" applies, branch to the Index Number associated with it, else branch to the Index Number associated with "NO." In some cases, *it will be seen,* the reader *is directed into an endless cycle by being referred* back to the beginning or to the very same operation (decision). This amounts to saying "you must wait until the condition changes and, for example, some requisite information has been furnished."

If the operations specified are actually performed, the corresponding task will be completed when the operation labeled "END" is reached as the next one. Provided the hypothetical execution of the preceding prescriptive directions has been totally faithful to their intended meaning (has been absolutely determined by them), the task will have been accomplished successfully.

Specifications for Tasks 01 - 19

TASK SPECIFICATION

Mission Context: Preparing a Surveyed Firing Chart

FDC Team Member(s): HCO and/or VCO

Individual Task: Numbering Blank Firing Chart*

Index No.	OPERATION: Action to be taken or Decision to be made		Branch to Index No.
010000	BEGIN		
1	Has long axis of chart been designated?		
		YES	2
		NO	0
2	Orient chart so that long axis corresponds to indicated cardinal direction.		
3	*Have initial reference coordinates* been given?		
		YES	4
		NO	5
4	Do they designate LLHC?		
		YES	6
		NO	5
5	Determine intersection of grid lines at center of chart; point to assure continuing identification.		7

* *Not applicable to Grid Zone Convergence Con-vergence Condition.*

Index No.	OPERATION: Action to be taken or Decision to be made		Branch to Index No.
010060	Determine grid lines forming lower left hand corner of chart.		
7	Using 4H pencil write (¼" high) the first two digits associated with (e.g., below) the identified easting grid line; write the next two digits associated with (e.g., left of) the identified northing grid line.		
8	Is there an easting grid line remaining to be labeled?		
		YES	9
		NO	19
9	Is the next grid line (N $\pm$ 1) the last one (farthest East) on the chart?		
		YES	8
		NO	10
10	Is it to the right (East) of the one that was labeled last on this axis?		
		YES	11
		NO	15
11	Add 1 to the digit pair immediately to the left (West) of the line to be labeled now.		
12	Is the sum equal to 100?		
		YES	13
		NO	14
13	Drop the "1" and retain only the "00".		
14	Using 4H pencil write (¼" high) the two digit sum in association with the next grid line to the right (East) of the last labeled one on this axis.		
15	Was the easting line labeled last assigned "00"?		
		YES	16
		NO	17
16	For calculational purposes only let 00 = 100.		
17	Subtract 1 from the digit pair immediately to the right (East) of the one to be labeled now.		
18	Using 4H pencil write (¼" high) the two digit remainder in association with the next grid line to the left (West) of the last labeled one on this axis.		8
19	Is there a northing grid line remaining to be labeled?		
		YES	20
		NO	30
20	Is the next grid line (N $\pm$ 1) the last one (farthest North) on the chart?		
		YES	19
		NO	21
21	Is it above the one that was labeled last on this axis?		
		YES	22
		NO	26
22	Add 1 to the digit pair immediately below the line to be labeled now.		
23	Is the sum equal to 100?		
		YES	24
		NO	25
24	Drop the "1" and retain only the "00".		
25	Using 4H pencil write (¼" high) the two digit sum next to the left end of the grid line immediately above (North) of the one labeled last on this axis.		19
26	Was the northing grid line lab labeled last assigned "00"?		
		YES	27
		NO	28
27	For calculational purposes only let 00 = 100.		
28	Subtract 1 from the digit pair immediately above (North) the line to be labeled now.		
29	Using 4H pencil write (¼" high) the two digit remainder next to the left end of the grid line immediately below (South) the last labled one on this axis.		19
010300	END		

TASK SPECIFICATION

Mission Context: Preparing a Surveyed Firing Chart

FDC Team Member(s): HCO and/or VCO

Individual Task: Plotting Critical and Non-Critical Points

Index No.	OPERATION: Action to be taken or Decision to be made		Branch to Index No.
020000	BEGIN		
1	Has at least one item of relevant information been given, received and stored?		
		YES	2
		NO	0
2	Do any points remain to be plotted (data in storage)?		
		YES	3
		NO	47

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
020030	Select next item of data in storage.	
4	Determine easting grid line whose numbers correspond to the first two digits of the easting (first) digit group.	
5	Determine northing grid line whose numbers correspond to the first two digits of the northing (second) digit group.	
6	On the chart determine the intersection of the two previously identified grid lines.	
7	Assure continuing identification of grid square (e.g., mark with pencil or pin, or point) that lies NE of the identified intersection.	
8	Is chart scale 1:25,000?	
	YES	9
	NO	10
9	Select 1:25,000 scale on coordinate square.	11
10	Select 1:50,000 scale on coordinate square.	
11	Looking straight down, place 0/0 point of coordinate sqare (meter/yards held legible side up) precisely over the identified intersection, and align horizontal scale edge with northing grid line.	
12	Still looking straight down and maintaining established alignment move square East (right) until scale reading (to the nearest 10 M) corresponding to the last two digits in easting (first) digit group lies over the identified easting grid line.	
13	Is point to be plotted a non-critical point?	
	YES	16
	NO	14
14	On scale estimate visually the precise location of the third digit within the bracketing scale graduation; precisely adjust scale so that this location lies over the easting grid line.	
15	Select pin and place into chart at a point opposite the vertical (northing) scale that corresponds to the last three digits of the northing (second) digit group; estimate precise location of the last digit within bracketing graduations as before.	17
16	Select pin and place into chart at a point opposite vertical (northing) scale that corresponds to the last two digits (to nearest 10 M) of the northing (second) digit group.	
17	Leaving clear, precise pinhole remove and store pin.	
18	Select straight edge and place horizontally so that pinhole made last is precisely bisected.	
19	Is pinhole just made located within 80 M or less of a grid line or marked point?	
	YES	20
	NO	21
20	Rotate straight edge 45° around pinhole center.	
21	Is point in question a maneuver check point?	
	YES	23
	NO	22
22	Is point in question a target located by firing?	
	YES	24
	NO	25
23	Select blue pencil.	26
24	Select red pencil.	26
25	Select 4H pencil.	
26	Draw a line from a point 190 M left of pinhole to one 40 M left of pinhole, then skip to 40 M right of pinhole and draw line to point 190 M right of pinhole.	
27	Has tick mark (4 lines) been completed?	
	YES	29
	NO	28
28	Rotate straight edge 90° around pinhole center.	26
29	Does completed tick mark represent a battery location?	
	YES	30
	NO	35
30	Is it A-Battery?	
	YES	31
	NO	32
32	Using red pencil mark "A" (¼" high) in upper right quadrant of tick mark.	46
33	Using 4H pencil mark "B" (¼" high) in upper right quadrant of tick mark.	46

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
020340	Using blue pencil mark "C" (¼" high) in upper right quadrant of tick mark.	46
35	Is it a radar location?	
	YES	36
	NO	37
36	Using green pencil mark (¼" high) in upper right quadrant of tick mark.	46
37	Is it a registration point location?	
	YES	38
	NO	39
38	Using 4H pencil write "REG PT" (¼" high) plus number assigned to it in the upper right quadrant of the tick mark.	46
39	Is it an OP location?	
	YES	40
	NO	41
40	Using 4H pencil write observer's identification (¼" high) in the upper right quadrant of the tick mark.	46
41	Is it a target location?	
	YES	42
	NO	43
42	Using 4H pencil write the three-digit identification number (¼" high) in the upper right quadrant of the tick mark; place optional information in upper left and/or lower right quadrant.	46
43	Is it a maneuver check point?	
	YES	44
	NO	45
44	Using 4H pencil write the one-digit identification number (¼" high) in the upper right quadrant of the tick mark and draw a tight circle around it.	46
45	Using 4H pencil write appropriate identification (numbers and/or symbols ¼" high) in upper right quadrant of tick mark.	
46	Obtain altitude for the identified point and, using 4H pencil, write three-digit altitude (¼" high) in the lower left quadrant of the tick mark.	2
020470	END	

TASK SPECIFICATION

Mission Context: Preparing a Surveyed Firing Chart

FDC Team Member(s): HCO and/or VCO

Individual Task: Constructing Azimuth Indexes

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
030000	BEGIN	
1	Is there a tick mark remaining for which an azimuth (Az) index is to be constructed?	
	YES	2
	NO	55
2	Select pin and place vertically and securely into center of tick mark in question.	
3	Is the cardinal direction from which the next Az index is to be established North (0 or 6400 ₥)?	
	YES	6
	NO	4
4	Is the cardinal direction from which the next Az index is to be established East (1600 ₥)?	
	YES	18
	NO	5
5	Is the cardinal direction from which the next Az index is to be established South (3200 ₥)?	
	YES	25
	NO	32
6	Plot easting of tick mark center in question as far North on chart grid as possible (within reach of RDP range arm); place pin precisely to mark location.	
7	Place RDP vertex against pin in reference tick mark.	
8	Rotate RDP until left edge of range arm is tight against last placed pin.	
9	Select pin and place in chart at 0 graduation on Az Scale on RDP arc.	
10	Without disturbing any pins, lift RDP, rotate clockwise beyond last placed pin, reposition RDP vertex on pin in reference tick mark, and push left edge of range arm against last placed pin.	
11	Remove last placed pin, and using wedge sharpened 6H pencil draw a 2" line bisecting the pinhole.	
12	Above the last drawn line and slightly to right of pinhole write (¼" high) the reference tick mark's identification plus "AZO."	

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
030130	Return left edge of RDP range arm to position it against the pin placed in 030060.	
14	Select pin and place in chart at 400 ₥ graduation on Az scale on RDP arc.	
15	Without disturbing any pins, lift RDP, rotate clockwise beyond last placed pin, re-position RDP vertex on pin in reference tick mark and push left edge of range arm against last placed pin.	
16	Remove the two last placed pins, and using wedge sharpened 6H pencil draw a 2" line bisecting the last made pinhole.	
17	Above the last drawn line and slightly to the right of the pinhole write (¼" high) the reference tick mark identification plus "AZ 6000."	39
18	Plot northing of reference tick mark center as far East on chart grid as possible; place pin precisely to mark location.	
19	Place RDP vertex against pin in reference tick mark.	
20	Rotate RDP until left edge of range arm is tightly against last placed pin.	
21	Select pin and place into chart at 600 ₥ graduation on Az scale on RDP arc.	
22	Without disturbing any pins, lift RDP, rotate clockwise beyond last placed pin, re-position RDP vertex on pin in reference tick mark and push left edge of range arm against last placed pin.	
23	Remove the two last placed pins, and using 6H wedge sharpened pencil draw a 2" line bisecting the last made pinhole.	
24	Above the last drawn line and slightly to the right of the pinhole write (¼"high) the reference tick mark's identification plus "AZ 1000."	39
25	Plot easting of reference tick mark center as far South on chart as possible (within reach of RDP range arm); place pin precisely to mark location.	
26	Place RDP vertex against the pin in the reference tick mark.	
27	Rotate RDP until left edge of range arm is tight against last placed pin.	
28	Select pin and place in to chart at 200 ₥ graduation on Az scale on RDP arc.	
29	Without disturbing any pins, lift RDP, rotate clockwise beyond the last placed pin, re-position RDP vertex on pin in reference tick mark and push left edge of range arm against last placed pin.	
30	Remove the two last placed pins, and using wedge sharpened 6H pencil draw a 2" line bisecting the last made pinhole.	
31	Above last drawn line and slightly to right of pinhole write (¼" high) the reference tick mark's identification plus "AZ 3000."	39
32	Plot northing of reference tick mark center as far West on chart grid as possible (within reach of range arm); place pin precisely to mark location.	
33	Place RDP vertex against pin in reference tick mark.	
34	Rotate RDP until left edge of range arm is tightly against the last placed pin.	
35	Select pin and place in chart at 800 ₥ graduation on Az scale on RDP arc.	
36	Without disturbing any pins, lift RDP, rotate clockwise beyond last placed pin, re-position RDP vertex on pin in reference tick mark and push left edge of range arm against the last placed pin.	
37	Remove the two last placed pins, and using wedge sharpened 6H pencil draw a 2" line bisecting the last made pinhole.	
38	Above last drawn line and slightly to right of pinhole write (¼" high) the reference tick mark's identification plus "AZ 4000."	
39	Have relevant Az indexes at 0 ₥, 1000 ₥, and 6000 ₥ been constructed?	
	YES	40
	NO	4
40	Is another supplementary Az index required?	
	YES	41
	NO	1

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
030410	Determine previously established Az index whose value is ± 1000 ₥ from supplementary index to be marked now.	
42	Is ₥ value of the selected previous Az index less than the ₥ value of the index to be marked now?	
	YES	43
	NO	49
43	Place the RDP vertex against the pin in the reference tick mark.	
44	Align 1000 ₥ graduation of Az scale on RDP arc with the selected previous Az index.	
45	Select pin and place into chart at 0 ₥ graduation of Az scale on RDP arc.	
46	Without disturbing any pins, lift RDP, rotate clockwise beyond last placed pin, re-position RDP vertex on pin in reference tick mark an push left edge of range arm against last placed pin.	
47	Remove last placed pin, and using wedge sharpened 6H pencil draw 2" line bisecting the last made pinhole.	
48	Above the last drawn line and slightly to right of pinhole write (¼" high) the reference tick mark's identification plus "AZ" and the sum of 1000 and the ₥ value of the selected previous Az index.	40
49	Place RDP vertex against pin in reference tick mark.	
50	Align 0 ₥ graduation of Az scale on RDP arc with the selected previous Az index.	
51	Select pin and place into chart at 1000 ₥ graduation of Az scale on RDP arc.	
52	Without disturbing any pins, lift RDP, rotate clockwise beyond last placed pin, re-position RDP vertex on pin in reference tick mark and push left edge of range arm against last placed pin.	
53	Remove last placed pin, and using wedge sharpened 6H pencil draw a 2" line bisecting the last made pinhole	
54	Above the last drawn line and slightly to right of pinhole write (¼" high) the reference tick mark's identification plus "AZ" and the value of the selected previous Az index minus 1000.	40
030550	END	

TASK SPECIFICATION

Mission Context: Preparing a Surveyed Firing Chart

FDC Team Member(s): HCO and/or VCO

Individual Task: Constructing Deflection Indexes (Referred Df = 3200 ₥)

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
040000	BEGIN	
1	Is there a tick mark remaining for which a deflection (Df) index is to be constructed?	
	YES	2
	NO	60
2	Place pin vertically and securely into center of tick mark in question.	
3	Has Az of lay been given?	
	YES	4
	NO	3
4	Is Az of lay close to principal direction of fire N (0 Or 6400 ₥)?	
	YES	7
	NO	5
5	Is Az of lay close to principal direction of fire E (1600 ₥)?	
	YES	12
	NO	6
6	Is Az of lay close to principal direction of fire S (3200 ₥)?	
	YES	20
	NO	25
7	Plot easting of reference tick mark center as far North on chart grid as possible (within reach of range arm); select pin and place precisely to mark location.	
8	Place RDP vertex against pin in reference tick mark.	
9	Rotate RDP until left edge of range arm is tightly against last placed pin.	
10	Select pin and place into chart either at 0 graduation on the Az scale on the RDP arc (temporary Az 0) or at the 400 ₥ graduation (temproary Az 6000).	

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
040110	Rotate RDP clockwise until the sum of the chosen pin location (0 or 6000) and the Az scale graduation opposite the pin equals the stated Az of lay.	33
12	Plot northing of reference tick mark center as far East on chart as possible (within reach of range arm); select pin and place precisely to mark location.	
13	Place RDP vertex against pin in reference tick mark.	
14	Rotate RDP until left edge of range arm is tightly against the last placed pin.	
15	Select pin and place into chart opposite the 600 ₥ graduation on the Az scale on the RDP arc (temporary Az 1000).	
16	Is announced Az of lay between 2000 - 3000 ₥?	
	YES	17
	NO	19
17	Rotate RDP clockwise until 1000 ₥ graduation on the Az scale is precisely aligned with the last placed pin.	
18	Without moving RDP, remove last placed pin and place it into chart opposite the 0 ₥ graduation on the Az scale (temporary Az 2000).	
19	Rotate RDP clockwise until the sum of the pin location (1000 or 2000) and the Az scale graduation opposite the pin equals the stated Az of lay.	33
20	Plot easting of reference tick mark center as far South on chart grid as possible (within reach of range arm); select pin and place precisely to mark location.	
21	Place RDP vertex against pin in reference tick mark.	
22	Rotate RDP until left edge of range arm is tightly against last placed pin.	
23	Select pin and place into chart opposite the 200 ₥ graduation on the Az scale on RDP arc (temporary Az 3000).	
24	Rotate RDP clockwise until the sum of the pin location (3000) and the Az scale graduation opposite the pin equals the stated Az of lay.	33
25	Plot northing of reference tick mark center as far West on chart grid as possible (within reach of range arm); select pin and place precisely to mark location.	
26	Place RDP vertex against pin in reference tick mark.	
27	Rotate RDP until left edge of range arm is tightly against last placed pin.	
28	Select pin and place into chart opposite the 800 ₥ graduation on the Az scale on the RDP arc (temporary Az 4000).	
29	Is announced Az of lay between 5000 - 6000 ₥?	
	YES	30
	NO	32
30	Rotate RDP clockwise until the 1000 ₥ graduation on the Az scale is precisely aligned with the last placed pin.	
31	Without moving RDP, remove last placed pin and place it into chart opposite the 0 ₥ graduation on the Az scale (temporary Az 5000).	
32	Rotate RDP clockwise until the sum of the pin location (4000 or 5000) and the Az scale graduation opposite the pin equals the stated Az of lay.	
33	Without moving RDP, move last placed pin to a point opposite the 200 ₥ graduation on the deflection (Df) scale on the RDP arc; push down straight and securely.	
34	Without disturbing any pins, lift RDP, rotate clockwise beyond last placed pin, reposition RDP vertex on pin in reference tick mark and push left edge of range arm against last placed pin.	
35	Remove the two last placed pins, and using wedge sharpened 6H pencil draw a 2" line bisecting the last made pinhole.	
36	Did reference tick mark represent A-Battery?	
	YES	38
	NO	37
37	Did reference tick mark represent B-Battery?	
	YES	39
	NO	40
38	Select red pencil.	41

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
040390	Select 4H pencil.	41
40	Select blue pencil.	
41	Remove RDP and draw arrow head pointing toward reference tick mark so that arrow tip will be 1/8" outward from pinhole in last drawn line.	
42	Is selected pencil red?	
	YES	44
	NO	43
43	Is selected pencil 4H?	
	YES	45
	NO	46
44	Horizontally across outer end of last drawn line write "A 3" (¼" high).	47
45	Horizontally across outer end of last drawn line write "B 3" (¼" high).	47
46	Horizontally across outer end of last drawn line write "C 3" (¼" high).	
47	Is there another supplementary Df index to be constructed?	
	YES	48
	NO	1
48	Place RDP vertex against pin in reference tick mark.	
49	Rotate RDP until 0 ₥ graduation on Df scale on RDP arc is precisely aligned with the last constructed Df index.	
50	Was the last Df index labeled "0"?	
	YES	52
	NO	51
51	Select pin an place into chart opposite the 1000 ₥ graduation on the Df scale on RDP arc; push down straight and securely.	
52	Select pin and place into chart opposite the 400 ₥ graduation on the Df scale on RDP arc; push down straight and securely.	
53	Without disturbing any pins, lift RDP, rotate clockwise beyond last placed pin, reposition RDP vertex on pin in reference tick mark and push left edge of range arm against last placed pin.	
54	Remove last placed pin, and using wedge sharpened 6H pencil draw a 2" line bisecting the last made pinhole.	
55	Select same pencil used for labeling primary Df index.	
56	Remove RDP and draw arrow head pointing toward reference tick mark so that arrow tip will be 1/8" outward from pinhole in last drawn line.	
57	Was last Df index labeled "0"?	
	YES	58
	NO	59
58	Horizontally across outer end of last drawn line write capital letter as for primary index and "6."	47
59	Horizontally across outer end of last drawn line write capital letter as for last Df index while subtracting 1 from accompanying number of that last Df index.	
040600	END	

TASK SPECIFICATION

Mission Context: Call for Fire - Adjust Fire Phase

FDC Team Member(s): HCO and/or VCO

Individual Task: Plot Target - Grid Coordinates Method

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
051000 through 051110	Equivalent to: Perform 020040 through 020160.	

TASK SPECIFICATION

Mission Context: Call for Fire - Adjust Fire Phase

FDC Team Member(s): HCO and/or VCO

Individual Task: Polar Plot of Target

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
052000	BEGIN	
1	Has FO given direction and distance to target?	
	YES	2
	NO	0
2	Has FO shifted from pre-plotted position and given a new (six digit) position?	
	YES	3
	NO	5
3	Plot FO's (critical point) position: perform 020040 through 020150.	
4	Establish FO's Az index(es): as needed perform 03000 through 03055.	
5	Place vertex of RDP precisely against pin in FO's position.	

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
052060	Align a graduation on Az scale of RDP arc with appropriate observer's Az index whose first digit (in 4-digit group) equals the first digit of the given direction (4-digit group).	
7	Rotate RDP until the sum of the Az index and of the Az scale graduation above it equals the given direction; estimate visually as precisely as possible.	
8	Select pin and place into chart tightly against left edge of RDP range arm at a point corresponding to stated distance.	
9	Push pin into chart vertically and securely.	
052100	END	

TASK SPECIFICATION

Mission Context: Call for Fire - Adjust Fire Phase

FDC Team Member(s): HCO and/or VCO

Individual Task: Plot Target by Shift from Known Point

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
053000	BEGIN	
1	Have target location data been provided?	
	YES	2
	NO	0
2	Store information.	
3	On chart identify the known point that has been specified.	
4	Select target grid and insert pin through center.	
5	Place pin (in target grid) precisely into center of known point tick mark.	
6	Rotate target grid so that arrow tip points North and so that any one target grid line is precisely aligned with any chart grid line.	
7	Select pin and place into chart precisely at the 0 ₥ graduation of the scale around target grid circumference (above arrow tip).	
8	Rotate target grid until a mil scale graduation equivalent to specified direction is precisely aligned with last placed pin.	
9	Select pin(s) and tack target grid to chart on side away from expected activity (below).	
10	Select pin.	
11	Move pin laterally from center of target grid in the specified direction (L or R) along the center line that is perpendicular to the arrow until the distance of pin from center of target grid (each line = 100) equals the specified lateral shift.	
12	Move pin precisely vertically from point identified in the last step in the direction specified (add or +: toward arrow head; drop or -: toward arrow tail) until the vertical distance covered (each line = 100) equals the specified range value.	
13	Push pin vertically and precisely into point reached so as to keep it securely in place.	
053140	END	

TASK SPECIFICATION

Mission Context: Call for Fire - Adjust Fire Phase

FDC Team Member(s): HCO

Individual Task: Determine Range with RDP

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
060000	BEGIN	
1	Has target location been established?	
	YES	2
	NO	0
2	Select pin and push vertically into precise center of tick mark representing the battery in question.	
3	Place vertex of RDP precisely against last placed pin.	
4	Rotate RDP counterclockwise until left edge of range arm is tight against previously placed target pin.	
5	Is chart scale 1:25,000?	
	YES	6
	NO	7
6	On RDP range arm read range in meters on the scale at the point of the target pin location; estimate visually to the nearest 10 M.	8
7	On RDP range arm read range in meters on the scale at the point of the target pin location and divide reading by 2;estimate visually to nearest 10 M.	
8	Store range value.	
060090	END	

TASK SPECIFICATION

Mission Context: Call for Fire - Adjust Fire Phase

FDC Team Member(s): HCO

Individual Task: Determine Deflection with RDP

Index No.	OPERATION: Action to be taken or Decision to be made		Branch to Index No.
070000	BEGIN		
1	Has target been pinned and range determined?		
		YES	2
		NO	060000
2	On RDP arc determine value on deflection (Df) scale for graduation that coincides with a Df index for the Battery in question; estimate visually to nearest mil.		
3	Multiply value of Df index used by 1000 and add Df scale reading from last step; sum is Df.		
4	Store deflection value.		
070050	END		

TASK SPECIFICATION

Mission Context: Call for Fire - Adjust Fire Phase

FDC Team Member(s): HCO

Individual Task: Giving Range and Deflection to Battery Computer(s)

Index No.	OPERATION: Action to be taken or Decision to be made		Branch to Index No.
080000	BEGIN		
1	Is communication channel currently in use?		
		YES	0
		NO	2
2	Announce (1) phonetic alphabet code for Battery in question, (2) "range" and (3) retrieved value of range from 060080.		
3	Does Battery Computer read back correctly?		
		YES	4
		NO	2
4	Announce (1) "deflection" and (2) retrieved value of deflection from 070040.		
5	Does Battery Computer read back correctly?		
		YES	6
		NO	4
080060	END		

TASK SPECIFICATION

Mission Context: Call for Fire - Adjust Fire Phase

FDC Team Member(s): HCO

Individual Task: Determine Angle T

Index No.	OPERATION: Action to be taken or Decision to be made		Branch to Index No.
090000	BEGIN		
1	Was target established by shift from known point?		
		YES	2
		NO	3
2	Shift previously used target grid so that its center (with pin through it) is precisely over plotted target; push in straight and securely.		5
3	Select target grid and pin.		
4	Push pin through center of target grid and place pin precisely into target pinhole; push down to secure.		
5	Orient target grid so that arrow head points up (N on chart); precisely align any target grid line with any chart grid line underneath.		
6	Select pin and place into chart opposite 0 ₥ graduation on peripheral target grid scale.		
7	Rotate target grid until direction value given by FO (i.e., Az) is aligned with last placed pin; secure target grid with pin(s) to maintain orientation.		
8	With RDP vertex on pin representing Battery in question, rotate RDP until left edge of range arm is tight against pin in target grid center.		
9	Is arrow tip on target grid visible?		
		YES	10
		NO	11
10	Select the smaller angle formed by the arrow tip on the target grid and the left edge of RDP range arm; count the number of mils between arrow tip and left edge in 100 ₥ units (to nearest 100 ₥).		12
11	Select the smaller angle formed by the arrow tail on the target grid and left edge of RDP range arm; count the number of mils between arrow tail and left edge in 100 ₥ units (to nearest 100 ₥).		
12	Store obtained Angle T.		
090130	END		

TASK SPECIFICATION

Mission Context: Call for Fire - Adjust Fire Phase

FDC Team Member(s): VCO

Individual Task: Determining Vertical Interval from Map

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
101000	BEGIN	
1	On map locate square having the same coordinates as correspon- ding square on chart grid that contains target location.	
2	Select 1:50,000 scale on coordinate square.	
3	Looking straight down, place 0/0 point of coordinate square (meters/yards held legible side up) precisely over lower left corner of identified square, and align lower horizontal scale on coordinate square with north- ing grid line of identified intersection.	
4	Still looking straight down and maintaining established alignment, move coordinate square East (right) until scale reading (to nearest 10 M) corresponding to last two digits in easting (first) tar- get digit group lies over the easting line of identified intersection.	
5	Select pin and place into map at a point opposite the verti- cal (northing) scale on the coordinate square that cor- responds to the last two digits of the northing (second) target digit group.	
6	Visually identify upper and lower contour lines on map which form band that contains the target.	
7	On map determine altitude values for upper and lower contour lines.	
8	Add ½ of difference (upper minus lower contour line altitude) to lower contour line altitude to obtain target altitude; remove pin from map.	
9	Is target altitude greater than altitude of Battery in question?	
	YES	10
	NO	11
10	Subtract Battery altitude from target altitude and label the resultant value with a positive (+) sign.	
11	Subtract target altitude from Battery altitude an label the resultant value with a negative (-) sign.	
12	Store vertical interval (VI).	
101130	END	

TASK SPECIFICATION

Mission Context: Call for Fire - Adjust Fire Phase

FDC Team Member(s): VCO

Individual Task: Determine Vertical Interval Via Vertical Shift

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
102000	BEGIN	
1	On chart determine altitude of known point or observer's loca- tion from which shift is occurring.	
2	Did information furnished by observer include a vertical component ("up" or "down" and value?	
	YES	3
	NO	6
3	Was given value preceded by "up"?	
	YES	4
	NO	5
4	Add given value to altitude of known point.	8
5	Subtract given value from altitude of known point.	8
6	Was omission (probably) intentional?	
	YES	7
	NO	0
7	Altitude of known point equals target altitude.	
8	Is target altitude greater than altitude of Battery in question?	
	YES	9
	NO	10
9	Subtract Battery altitude from target altitude and label resul- tant value with a positive (+) sign.	11
10	Subtract target altitude from altitude of Battery in question and label the resultant value with a negative (-) sign.	
11	Store vertical interval (VI) data.	
102120	END	

TASK SPECIFICATION

Mission Context: Call for Fire - Adjust Fire Phase

FDC Team Member(s): VCO

Individual Task: Compute Site

Index No.	OPERATION: Action to be taken or Decision to be made		Branch to Index No.
111000	BEGIN		
1	Select proper Graphical Site Table (GST).		
2	Is charge number given in fire order shown on slide (center) of GST?		
		YES	4
		NO	3
3	Remove slide of GST and re-insert with other side showing.		
4	Move manufacturer's hair line (MHL) to a value on the D scale that corresponds to the absolute value of the VI.		
5	Visually select scales on slide labeled with charge in question.		
6	Has VI a positive sign?		
		YES	7
		NO	8
7	Without changing MHL setting, move slide until value of established target range on the TAG (black) scale is under MHL.		9
8	Without changing MHL setting, move slide until value of established target range an the TBG (red) scale is under MHL.		
9	Read value on D scale opposite M-gage point.		
10	Was TAG (black) scale used?		
		YES	11
		NO	12
11	Label value read at gage point positive (+).		13
12	Label value read at gage point negative (-).		
13	Was Rg change-over point on scale used (TAG or TBG) reached or exceeded?		
		YES	14
		NO	15
14	Round off Rg to next lower value shown numerically on scale.		
15	Approximately divide VI (in meters) by Rg/1000 to estimate decimal point.		
16	Store site data.		
111170	END		

TASK SPECIFICATION

Mission Context: Call for Fire - Adjust Fire Phase

FDC Team Member(s): VCO

Individual Task: Announcing Site

Index No.	OPERATION: Action to be taken or Decision to be made		Branch to Index No.
120000	BEGIN		
1	Is communication channel in use?		
		YES	0
		NO	2
2	Retrieve site from 111160.		
3	Announce (1) "site", (2) phonetic alphabet code for Battery in question, and (3) value of site.		
4	Does Battery Computer read back correctly?		
		YES	5
		NO	3
120050	END		

TASK SPECIFICATION

Mission Context: Call for Fire - Adjust Fire Phase

FDC Team Member(s): Computer(s)

Individual Task: Record Fire Order and Announce Fire Mission

Index No.	OPERATION: Action to be taken or Decision to be made		Branch to Index No.
130000	BEGIN		
1	Store in order received: (1) observer identification (2) warning order (3) target location (4) target description (5) method of engagement (6) authentication.		
2	Store in order received: (1) changes, if any, in standard elements of fire order, and (2) added, non-standard elements.		
3	Is communication channel clear?		
		YES	4
		NO	3
4	Announce to Battery in order: (1) "fire mission," (2) "battery adjust," (3) "charge" plus value given in fire order (if necessary, address standard fire commands).		
5	Does RTO read back correctly?		
		YES	6
		NO	4
130060	END		

TASK SPECIFICATION

Mission Context: Call for Fire - FFE Phase

FDC Team Member(s): Computer(s)

Individual Task: Re-Announcing Number of Rounds and Fuze to Battery

Index No.	OPERATION: Action to be taken or Decision to be made		Branch to Index No.
140000	BEGIN		
1	Have changes been made in previously established fire order?		
		YES	2
		NO	3
2	Note changes, if any, affecting number of rounds to be fired and/or fuze type to be used.		4
3	Retrieve from established fire order and 130020: (1) number of rounds to be fired by Battery, and (2) fuze type to be used.		
4	Is communication channel clear?		
		YES	5
		NO	4
5	Announce: "battery," value from 140020 or 140030 plus "rounds," "fuze" plus type from 140020 or 140030, (add, if required, shell type).		
6	Does Battery RTO read back correctly?		
		YES	7
		NO	4
140070	END		

TASK SPECIFICATION

Mission Context: Call for Fire - Adjust Fire Phase

FDC Team Member(s): Computer(s)

Individual Task: Compute and Announce Deflection to Battery

Index No.	OPERATION: Action to be taken or Decision to be made		Branch to Index No.
150000	BEGIN		
1	Has currently valid deflection (Df) been received?		
		YES	3
		NO	2
2	Request Df from HCO.		1
3	Store Df data.		
4	Algebraically add previously established Df correction to last received/stored Df.		
5	Is communication channel clear?		
		YES	6
		NO	5
6	Announce: "deflection" and algebraic sum obtained in 150040.		
7	Does Battery RTO read back correctly?		
		YES	8
		NO	6
150080	END		

TASK SPECIFICATION

Mission Contxt: Call for Fire - Adjust and FFE Phases

FDC Team Member(s): Computer(s)

Individual Task: Compute Quadrant Elevation

Index No.	OPERATION: Action to be taken or Decision to be made		Branch to Index No.
161000	BEGIN		
1	Select proper Graphical Firing Table (GFT) for charge in fire order.		
2	Has a currently valid Rg value been received?		
		YES	4
		NO	3
3	Request data from HCO.		2
4	Set MHL on Rg scale to current Rg value; determine value on elevation scale which lies under previously marked line for corrected elevation setting.		
5	Store elevation.		
6	Determine 100/R value on 100/R scale that lies under MHL.		
71	Multiply 100/R by .2 to obtain 20/R.		
72	Divide 100/R by 5 to obtain 20/R.		
8	Store 20/R.		
9	Has site been received?		
		YES	11
		NO	10
10	Request site from VCO.		9
11	Is Ti or VT in effect?		
		YES	12
		NO	13
12	Retrieve elevation and 20/R; algebraically sum elevation, site and 20/R.		14
13	Retrieve elevation; algebraically sum elevation and site.		
14	Store QE.		
161150	END		

TASK SPECIFICATION

Mission Context: Call for Fire - FFE Phase

FDC Team Member(s): Computer(s)

Individual Task: Deriving Time or Fuze Setting

Index No.	OPERATION: Action to be taken or Decision to be made		Branch to Index No.
170000	BEGIN		
1	On previously selected GFT is MHL still on current Rg?		
		YES	3
		NO	2
2	Set MHL to current Rg value on Rg scale.		
3	Is VT in effect?		
		YES	4
		NO	5
4	On FS M564 scale read value to nearest whole second that lies under the previously marked line for corrected time (fuze) setting.		
5	On FS M564 scale read value to nearest .1 second that lies under the previously marked line for corrected time (fuze) setting.		
6	Store obtained value.		
170070	END		

TASK SPECIFICATION

Mission Context: Call for Fire - FFE Phase

FDC Team Member(s): Computer(s)

Individual Task: Announcing FFE Data to Battery

Index No.	OPERATION: Action to be taken or Decision to be made		Branch to Index No.
180000	BEGIN		
1	Retrieve: (1) Df from 150040, (2) time or FS from 170060, (3) QE from 161140.		
2	Is communication channel clear?		
		YES	3
		NO	2
3	Announce in order: (1) "time" plus value retrieved in 180010, (2) "deflection" plus value retrieved in 180010, (3) "quadrant" plus value retrieved in 180010.		
4	Does Battery RTO read back correctly?		
		YES	5
		NO	3
180050	END		

TASK SPECIFICATION

Mission Context: Call for Fire - Adjust Fire Phase

FDC Team Member(s): Computer(s)

Individual Task: Announcing Quadrant Elevation (QE)

Index No.	OPERATION: Action to be taken or Decision to be made		Branch to Index No.
190000	BEGIN		
1	Is communication channel clear?		
		YES	2
		NO	0
2	Is this the initial adjust round of this mission?		
		YES	3
		NO	4
3	Announce to Battery in order: (1) number of rounds given in fire order plus "rounds", (2) fuze type to be used during FFE plus "in effect," (3) "quadrant" plus value retrieved from 161140.		5
4	Announce to Battery: "quadrant" plus value retrieved from 161140.		
5	Does RTO read back correctly?		
		YES	6
		NO	2
190060	END		

APPROACHES TO ROUTINE DEVELOPMENT

The uses of precise, detailed, valid and reliable task specifications (TS) are manifold, and this has been pointed out from the beginning. More will be said about various uses in the next segment. If such uses are to be made and made routinely on an operational scale, efficient and economical approaches to the rapid development of quasi-algorithmic TS need to be established. The procedures followed in this present, exploratory effort were clearly not of that type. This effort was primarily a test, on a moderate scale, of the practical feasibility of something for which a priori only a strongly plausible rationale could be exhibited. Hence, procedures used (as described in the second segment of this report) were improvisations and of a makeshift character. The successful demonstration of the feasibility and practicality of quasi-algorithmic TS necessitates the outline delineation of a more systematic approach to development.

Some Background Considerations

As explained earlier, quasi-algorithms are an approximation to formal algorithms. While formal algorithms have many important uses in formal logic and in pure and applied mathematics, their most widely known application is the digital computer program. Quasi-algorithms are not exactly like formal algorithms, and quasi-algorithmic TS are not to be thought exactly like computer programs of either the digital or the analog type; neither are human beings exactly like either analog or digital computers. However, quasi-algorithmic TS and (particularly digital) computer programs, if not of the same genus and species are members of the same family or, perhaps, only order or class. For practical purposes they do share certain characteristics and introduce, at least, some similar problems.

Once it has been developed and validated (tested, verified) a quasi-algorithmic TS retains its specific validity and usefulness indefinitely. So long as there is no significant change in the type of task(s) to which it is applicable, the population on which it was validated, or the kind of use to which it is put its "shelf life" is indefinite. In a similar sense this is also true of computer programs. So long as there is, for example, no change in the way a pay-roll is computed, so long as there is no change in the computer (make, model, configuration) for which the program was written, and so long as there is no new or additional output requirement (e.g., summarize not only pay, taxes, deductions, etc., but also accumulated vacation and sick leave credits) the program may be used over and over again. However, changes of various types do occur over time, and programs must be "maintained", updated, augmented, and so on. There is a strong presumption that analogous changes will take place with respect to TS.

We had a specific example of a change even within the present exploratory effort. As explained earlier, the Battery Computer (in the FDC) no longer announces the number of rounds to be fired and the fuze type when first alerting his Battery to a fire mission (Task 13), but only on first giving Quadrant Elevation (Task 19). A change such as this one is conceptually not difficult -- perhaps trivial, but does entail tedious rearrangements. Not only will the text of one or more operations change (in source as well receiving TS), but some operations may be eliminated and/or others added. Index Numbers in both TS may change. References to the "old" Index Numbers must be found and changed. Possibly a change in some sort of nomenclature may occur, or perhaps in a phrase used repeatedly throughout several TS. All of the instances of prior use must be found and the corrections made.

So long as TS information is stored in printed form any changes are likely to present a staggering clerical problem. The tracing of concatenated change effects through reams of printed paper is likely to entail labor costs that may well turn out to be greater in the long run than the original costs of developing the TS. The solution to this problem is suggested by the standard mode of dealing with computer programs. Storing the basic information in magnetic form via a computer simplifies the change procedures immensely and reduces attendant labor costs to a much more reasonable level. As is the case with computer programs, the stored information can be printed out or displayed on a cathode ray tube (CRT) at will. In addition, computer furnished clerical supports of assigning unique Index Numbers, of text editing, of searching, of locating incomplete or "open" branches (to name but an obvious few) can simplify and expedite original task specification development and validation (verification, testing) and provide similar simplification in useful applications of TS.

Storage and handling of TS information can be accomplished on almost any kind of general purpose digital computer. It can be done in a batch-processing mode or, with far greater convenience, on an individual terminal in a time-sharing mode. However, it can be argued that the "personal" type of micro-computer that is being currently introduced commercially offers important advantages. The chief advantages would seem to be (1) simplicity, (2) portability and (3) cost. These micro-computers have been designed for a market of minimal sophistication so that the operation of these devices does not demand or pre-suppose any substantial degrees of skills or knowledges on the part of prospective users. They require no special environments (air conditioning, electric power, etc.), weigh perhaps 20 - 30 lbs, occupy no more than one half of a desk top, and use ordinary tape-cassettes for mass information storage. They

are, therefore, clearly and easily portable and useable, for example, in any office or field environment with 115 V service. Lastly, costs of currently advertised commercial products tend to be about the same as for good quality electric typewriters (less than $1000).

If micro-computers can be assumed as a tool or helpmate for developers, maintainers and some users of TS, both, efficiency and economy will probably be achieved. Tape-cassette storage of substantive information guarantees its rapid and inexpensive reproducability. In principle, this information can be readily transferred to other information storage and handling environments. These considerations must be kept in mind as a practical backdrop for the development framework which follows.

Jobs/Tasks/Operations Inventories

The significance (by any sort of criterion) of all jobs or duty positions is not equal. Some can be said to be of major significance, while others are of little or no significance. This is equally true of individual tasks. For example, the computation of Site by the VCO can probably be considered as being highly significant, while the parroting of message traffic by the RTO is of little significance (though possibly of great importance to mission success). Similarly, some operations within individual tasks are significant (e.g., reading correct value of Site on GST) and others trivial (e.g., deciding whether the communication channel is in current use). However one might define "significant," it will be appreciated that there is no need to subject any and all job/task activities to analysis and detailed, quasi-algorithmic specification. Rather such analysis probably should be only selectively undertaken. The issue of the criteria for selection goes beyond the scope of this report.

Hayes, Meltzer and Wolf (1970) pointed out that substantive conclusions to be drawn from a data analysis, or the model (image or representation of reality) that emerges is very much dependent on the fine-grainedness of the data that are considered. Two models may be equally correct, though seemingly very different. For example, the structures apparent under a microscope at the highest and lowest levels of magnification will be very different, though both will be of the same object. As in the case of the microscope, it will not invariably be desirable to examine any and all human activity to the level of the (extremely) elementary operation. For many purposes it may suffice to stay at the level of the individual task (minimal "magnification" and maximal "area of view"). However, as in any structure, representation at all "levels of magnification" must have a cross-level coherence or internal, mutually consistent morphology.

If one considers, for example, Tasks 05 through 19 as specified in this report, it will be evident that a different sort of task identification, grouping of operations or structure would likely have been produced in an inventory derived from questioning MOS 13E personnel about "what they do." The problem of inventorying tasks so as to maintain a coherent morphology can be identified as requiring a solution, but the solution again goes beyond the scope of the present project.

A related problem that was addressed without a wholly satisfactory solution is the algorithmic or quasi-algorithmic representation of a group or team of interacting individuals. Unlike the serial activities of individuals such activities occur in parallel and with different degrees of interdependence and synchrony. In Figure 1 an approximate task plot was provided for a routine fire mission, but this graphic representation does not have the degree of rigor, for example, that would be required for computer implementation or simulation. An examination of pertinent literature (Miller, 1973; Varsonyi, 1977, 1978) suggests that Petri nets may provide the formal basis for a solution, and an attempt was made to develop an augmented Petri net in accordance with Peterson (1977) and Zisman (1978). A graphic depiction of Tasks 05 - 19 as an augmented Petri net rapidly becomes too complex and cumbersome, since input, processing and output nodes must be distinguished. A conversion of the net to an isomorphic table alleviates the problem only a little. A lengthier and more exhaustive examination of this problem will be necessary to assure feasibility of computer implementation of (including analytic/synthetic operations on) task structures of teams (groups rather than individuals).

Within the foregoing qualifications and identification of issues requiring further, more elaborate examination it is suggested that tasks as such be surveyed and inventoried first before proceeding to an uncritical, detailed analysis of any and all tasks (i.e., analysis to the level of operations). The criteria for proceeding to a detailed analysis will, no doubt, be somewhat contingent on the intended purposes. If, for instance, the purpose is one of assessment or prediction of team performance, the criticality to overall mission success might be considered a factor. If the purpose is training, statistics on a task's being a steady source of inadequate performance, or of being difficult to learn -- being a known instructional problem -- may be the more weighty factor. Whatever the criteria, however, only tasks for which there exists an adequate justification should be specified in detail in quasi-algorithmic form.

Analyst - Expert Collaboration

This segment of the report deals with suggestions that can be made at this stage of experience concerning approaches to effective, efficient and economical routine development of quasi-algorithmic TS.

So far the advantages of developing TS with the aid of micro-computers have been outlined. The host of implications carried by this recommendation is too large for a minutely detailed consideration, and it must be hoped that this missing information can be supplied by readers. Also, a selective subjection of tasks to detailed analysis was recommended. Within these two major framework considerations a practical procedure such as the following one seems indicated.

The time consuming technique used in this present exploratory effort of locating relevant documentation, analysing its content, synthesizing from it the gross algorithm, etc. is clearly very inefficient. A better technique will make an expert in a given subject-matter area available to the task analyst. The analyst will go to the expert's location so that requisite equipment and other resources will be available. The analyst will carry with him a portable micro-computer with key-board, CRT and tape-cassette reader/recorder.

For tasks in a list selected according to applicable criteria from a pre-established inventory, analyst and expert will now collaborate. The expert will define, explain and demonstrate as necessary exactly how a given task is accomplished. The expert will elicit all information needed to eliminate ambiguity, choice, equivocality and so forth through questions to the expert. Provisionally, operation-by-operation, segment-by-segment or branch-by-branch the analyst will begin to formulate the prescriptive directions and store them via the key-board in the computer. On completion of any major segment or of an entire task the (structured) stored information will be retrieved in its various permissible orders, reviewed, reformulated or revised. When expert and analyst agree that the stored formulations seem to meet the criteria for a proper quasi-algorithmic TS, they will go on to repeat the procedure for the next task on the list.

Ultimately the list of tasks will have been exhausted. A corresponding set of TS will have come into existence and be stored within the micro-computer. Next, these draft-specifications might be reviewed and revised for textual niceties and serious typographical errors. Then they will be ready for verification with several additional experts who will not include the original collaborator.

Rather than having to listen and read from the printed page as in procedures followed by the present authors, the expert will have the successive prescriptive directions presented to him on the CRT. He will not be distracted by irrelevant information such as, preceding and succeeding operations and lists of Index Numbers. This information will be invisible to him, but perform its role in linking individual operations (prescriptive directions) appropriately. As mistakes and deficiencies are uncovered or supplementary comments are made, they can be entered on the key-board and later retrieved in association with the operation(s) to which they apply.

When task specifications have been adequately verified, a final round of revisions will be made. Again they will be made directly via the key-board with computer-furnished clerical supports and with respect to information displayed on the CRT. Final versions of TS can be duplicated on tape-cassettes or printed out, or the information can be transferred to larger computers.

USES OF TASK SPECIFICATIONS

All of the uses of task specifications (TS) remain to be discovered as with any innovation. What can be discussed here are only some of them and with respect to development procedures.

Instruction

There is virtually universal agreement in the pertinent literature that the development of effective and efficient instruction must be based on carefully pre-established instructional objectives (see, e.g., Ammerman and Melching, 1966; Banathy, 1968; Briggs, 1970; Mager, 1961; Smith, 1964 a, b). Such predefined and properly stated objectives are necessary to orient the designer of the instruction and to assure complete coverage. These and related efforts are sometimes referred to as the "front-end analysis" in the planning and development of training. The implicit object of these efforts is to provide a "map" or a "blueprint" that can guide detailed instructional development.

With reference to explanations given in the first segment of this report it will be recognized that instructional objectives by themselves do not provide a complete and detailed "blueprint" of a learning task. The question of how these objectives can be attained is left begging, and instructional designers must fall back upon their intuition. Instructional objectives, at best, provide a sort of "architectural sketch;" it is only properly developed quasi-algorithmic (learning) task specifications that provide the full blueprint.

It must be stressed that quasi-algorithmic specifications of the learning task do not solve all of the instructional design and development problems. They do specify what must be done to accomplish the given task, but do not specify how the task executor (e.g., the trainee) can be controlled (guided, constrained) so as to perform any and all component operations properly. The learning task is not identical with the teaching task, although it contains essential information for the formulation of the latter (see Pask, 1975, Ch. 7).

When TS are being prepared for use in instructional development, the previously outlined procedures should be extended in two ways. First, as has been explained before, though a given TS may have been validated for a population of experts, the component prescriptive directions are unlikely to be of sufficient elementarity for a population of novices/students/trainees. This elementarity will need to be adjusted in collaboration with students from the population in question. Such an adjustment must not in the least change the structure of the prescriptive directions. Only those directions which are not comprehensible to students (they cannot tell what they are to do and/or how they are to do it) must be broken down into (replaced by) a more finely grained, structured set of operations. In effect, an operation that is elementary for the expert may constitute a mini-task for the student. In principle, the process of developing a quasi-algorithmic specification for the mini-task parallels that used for any task. The mini-task specification must be "patched" into the place formerly occupied by the original, non-elementary prescriptive direction.

The second additional development requirement arises when it is desired to take advantage of the diagnostic possibilities by quasi-algorithmic (learning) TS in adaptive forms of instruction (individualized instruction, computer administered instruction or CAI). Each operation in a TS resulting in a potentially observable outcome must be examined to determine the consequences of all types of possible mistakes. Ideally the implications of combinations of mistakes should also be determined. The object of these efforts is to develop a set of observable "symptoms" that point to specific causes in the students' learning task performance and inherently suggest the precise, required, remedial instructional action.

Assessment/Testing

All of the ways in which TS can be used in assessment undoubtedly have not yet been discovered. For example, there is an intuitive presumption that quasi-algorithms have a pertinence for adaptive, individualized or tailored testing as they do for instruction, but we have not established such a connection. Certain it is that there are applications in, both, normative and criterion-referenced testing.

So long as the elementarity of a given prescriptive direction (operation) or, in the aggregate, of an entire TS is relative to a defined population, the level of elementarity is capable of being scaled. Hence, a score based on that scale can express the standing of that person on that scale. Establishment of the scale as such will parallel the procedures used in conventional psychometrics.

With respect to criterion-referenced testing tasks (in the sense used herein) could constitute items or subtests in an achievement battery such as, skill qualifications tests (SQT's). In principle, a test administrator or observer could use the task specification (a) to pre-identify all observable intermediate outcomes and their values, and (b) to record, at least, success or failure at each observation point.

Not only could degree of mastery be ascertained, but an accurate diagnostic analysis coupled with specific recommendations for supplementary study could be provided. The degree of diagnostic detail desired will determine the amount of additional development necessary as in the case of instruction.

Duty/Task Structuring and Taxonomy

Quasi-algorithmic TS unlike the products of traditional approaches provide a reliable, verified foundation for data structures erected on them. They provide the foundation, for example, for meaningful task taxonomies. Given the application of a metric or semi-metric to a sound data structure the relative degrees of relationship among operations, among tasks and among jobs (duty positions) can be calculated. It is to be expected that the degree of such a relationship would express a degree of "transfer of mastery"[9/] of how much in a new task or duty position remains to be mastered by any incumbent who has already mastered another task or job.

Kingsley and Kopstein (1977), in an initial exploration, developed the concept of a dominance relation among occupational groupings. This relation imposes a partial order on a set of occupational entities (job families, jobs or duty positions, tasks, etc.) which can be viewed as an ordering according to "similarity." Also, a hierarchical structure among the occupational entities is established. The dominance relation and any other more elaborate taxonomic development require that each entity (job or task or operation) have associated with it a set of attributes ("characteristics") defining it. Clearly, the assignment of values to each attribute even in a pre-established set constitutes an additional development. However, attribute sets provide the basis for erecting more elaborate data structures and for the extraction of information from these structures. These issues are discussed in Part II of this report.

9/ This is not to be equated with the concept of transfer of training which expresses the savings in mean number of trials to learn a second task after learning a first one.

PART II.

A MODEL FOR STRUCTURING TASK SPECIFICATIONS

ABSTRACT REPRESENTATIONS OF TASK SPECIFICATIONS

Part I of this report has dealt with the ways and means for obtaining accurate and reliable specifications of human activities within certain military occupational duties. It was shown how quasi-algorithmic task specifications constitute an advance over traditional approaches, because they possess the very useful and important properties of specificity, generality and resultivity. Thus the quasi-algorithmic form of task-activity specification provides the basic, objective, detailed and valid information about the operations and their organization that comprise task accomplishment. The practical feasibility of developing and verifying quasi-algorithmic task descriptions/specifications was demonstrated.

In this Part II of the report we proceed to our exploration of the ways and means by which the full range of information in quasi-algorithmic task specifications may be elaborated, extracted and used. To be sure, some of the ways in which the obvious and "raw" information may be put to use have already been suggested in the preceding discussion of some uses of the task specifications (TS). However, these immediate and direct forms of information use represent only a small part of a far greater potential. That potential resides in data structures (models) being erected on the solid foundations of objectively verified TS. The precise kinds of structures to be erected on existing foundations -- as in the case of a building -- is primarily dependent on the uses intended for them. However, there are many possible uses; the different kinds of data structures and the information that can be extracted from them can serve in many personnel oriented management decision processes, or can themselves constitute certain management models.

The possibilities are certainly manifold and within each type of application there are numerous variants on the potential data exploitation. Unfortunately at this initial stage of exploration all of the possibilities can be neither identified nor fully characterized. At a comparable stage the present uses for digital computers, lasers, operations research methods, or any other innovation could also not be clearly and minutely foreseen. Nor could all of the development problems toward actual, smooth implementation be specified in advance. Every innovation needs a period of incubation to develop its potential, and it requires sustained development efforts during that period. This reminder may be necessary, because present efforts are limited to an initial exploration. Within the scope of the present investigation only some initial and major and important possibilities could be identified. Due to constraints on the scope of that exploration it could go no further than to characterize the issues for further research and development leading to potential operational applications. These issues could not be resolved within the present exploratory effort.

The following sections of this report proceed to the exploration of formal data structures erected on the quasi-algorithmic TS. As in all cases of mathematization, the abstraction into symbols of the underlying verbal formulations inevitably entails a loss of some information. At the same time symbolic forms make for mathematical tractability, i.e., manipulability of the data toward rigorous solutions of certain problems. Tractability of mathematical models has long been recognized to be directly related to the degree of abstraction they represent (see, e.g., Ackoff, 1962, pp. 109 - 110). Below it will be seen that some inversion of the information loss can be obtained by making explicit some characteristics or attributes of operations within TS. The logical and mathematical methodology outlined here below, incidentally, is a general one. While it is illustrated here in terms of operations within tasks, it is equally applicable to tasks within jobs or duty positions and to still more inclusive elements, and this should be kept in mind.

Representing a Task Specification in Terms of Attributes

Each of the task specifications given in Part I can be viewed as an ordered list of operations. To begin the mathematical formulation, let the operations in a task specification (TS) be symbolized by the small letter "o" with subscripts. Then the operations in a TS can be written as the ordered set,

$$(o_1, o_2, \ldots, o_m) ,$$

where m is the number of operations in the TS. It is convenient to represent this ordered set by the capital letter "O".

Then

1) $$O = (o_1, o_2, \ldots, o_m)$$

will represent the ordered set of operations in an arbitrary task specification. When a particular task specification is under discussion, the notation TS with a subscript is used. The subscript is the Index Number of the task specification given in Part I. The associated set of operations bears the subscript with the same index number. Thus, TS_{053000} and O_{053000} are the beginning of the task specification and of the set of operations of Task 053 of Part I titled, "Plot Target by Shift from a Known Point". For our purposes, no ambiguity results if the O's are not included in the subscript. Thus, TS_{053000} and O_{053000} become TS_{53} and O_{53}, respectively. With this notation, expression (1) for TS_{53} is written,

2) $$O_{53} = (o_2, o_3, \ldots, o_{13}).$$

Operations o_1 and o_{13} of TS_{53} are not included in the set O_{53} because they are decision points. Task specification 053000 is the main example used in what follows to illustrate the concepts developed and the issues surrounding these concepts.

To establish data structures and derive information from them requires a fundamental assumption to be made. This is the assumption that each operation in a task specification can be described in terms of attributes from a pre-selected set of attributes. Operations may be described by their possession of all or some of the attributes in the set. Let capital A designate the total set of attributes and the small letter "a", with subscripts, denote the individual attributes in A. The set A is an ordinary (unordered)

Table 3

Attributes for Illustrative Example

Hypothetical Attributes	Abbreviation
Short Term Memory	a_1
Reading Skill	a_2
Visual Acuity	a_3
Geometric Skill	a_4
Finger Dexterity	a_5
Orientation Skill	a_6
Numerical Skill	a_7
Eye-Hand-Finger Coordination	a_8
Precision/Accuracy	a_9
Color Discrimination	a_{10}
Form Perception	a_{11}
Stamina	a_{12}

set and, as is customary, is written as

3) $$A = \{ a_1, a_2, \ldots, a_n \} ,$$

where n is the number of attributes in the set A. To illustrate, Table 3 shows 12 attributes the operations in O_{53} may possess. In our judgment, based on the experience gained in deriving the TS of Part I, the 12 attributes in Table 3 are some of the attributes required to perform some of the operations in all of the TS. The number of attributes is small to permit hand computations to illustrate the theory. By no means is the list of attributes to be considered a definitive statement of attributes required to describe all of the operations in the set of TS. Their only purpose is to illustrate properties of the general model by a reasonably practical example. No particular relevance should be sought or seen in the results to be obtained by assuming the attribute set of Table 3.

The attributes in Table 3 are concisely represented by the set,

$$A = \{ a_1, a_2, \ldots, a_{12} \} .$$

The exact explication of each attribute is not important for our present purposes. Most of the attributes are hypothetical and self-explanatory, but a_6 and a_9 require some explanation. "Orientation Skill," attribute a_6 is a short way of stating the attribute associated with reading a map. It includes, for example, the ability to distinguish cardinal directions, read and plot coordinates, read and plot angles, etc. "Precision/Accuracy," attribute a_9 is an hypothetical measure of how well a_9 has to be performed.

Table 4 shows which attributes of Table 3 characterize each of the 12 operations of TS_{53}. As in the selection of the attribute set, this assignment of attributes to operations is hypothetical and for illustrative purposes only. However, the assignments are presumably not altogether unrealistic.

Table 4

Attributes of Operations in TS_{53}

Operation	Hypothetical Attributes
o_2	a_1, a_2
o_3	a_1, a_2, a_3, a_4
o_4	a_4, a_5
o_5	a_3, a_4, a_5, a_9
o_6	a_3, a_4, a_5, a_6, a_9
o_7	a_3, a_4, a_5, a_7
o_8	$a_3, a_4, a_5, a_6, a_8, a_9$
o_9	a_4, a_5, a_8
o_{10}	a_5
o_{11}	a_1, a_3, a_4, a_8, a_9
o_{12}	a_1, a_3, a_4, a_8, a_9
o_{13}	a_3, a_5, a_9

So far, two sets have been defined for a TS, O and A. Set O has m elements and A has n elements. Our fundamental assumption is that every operation o_i $(i = 1, 2, \ldots, m)$ possesses some amount of attribute a_j $(j = 1, 2, \ldots, n)$. Let r_{ij} represent the amount -- in some sense -- of attribute a_j possessed by operation o_i. For example, r_{23} is the amount of attribute a_3 required in operation o_2.

Three sets are now defined, O, A, and the set of r_{ij} values. Their interrelation can be displayed as an m by n matrix as shown in Figure 2. This matrix is defined as the Operations/Attributes (O/A)

Attributes

Operations	a_1	a_2	a_3	$\cdot \cdot \cdot$	a_n
o_1	r_{11}	r_{12}	r_{13}	$\cdot \cdot \cdot$	r_{1n}
o_2	r_{21}	r_{22}	r_{23}	$\cdot \cdot \cdot$	r_{2n}
o_3	r_{31}	r_{32}	r_{33}	$\cdot \cdot \cdot$	r_{3n}
$\cdot$	$\cdot$	$\cdot$	$\cdot$		$\cdot$
$\cdot$	$\cdot$	$\cdot$	$\cdot$		$\cdot$
$\cdot$	$\cdot$	$\cdot$	$\cdot$		$\cdot$
o_m	r_{m1}	r_{m2}	r_{m3}	$\cdot \; : \; :$	r_{mn}

Figure 2. O/A Matrix of a General TS

matrix associated with a TS. The notation $(O/A)_{53}$ means the O/A matrix corresponding to TS_{53}. Each of the rows in the O/A matrix of Figure 2 is a linear vector. If o_i is an arbitrary operation of the O/A matrix, it can be written as,

4) $$o_i = (r_{i1}, r_{i2}, \ldots, r_{in}),$$

where i can take on any one of m values. The linear vector is defined as the description of operation o_i in terms of the attribute set A. Therefore, each of the m rows in the O/A matrix is a description of an operation, and the sequence of m rows is a description of the entire TS.

The $(O/A)_{53}$ matrix is not shown at this point. However, its row labels would be the 12 elements of the set O given by (2), and its column labels would be the 12 elements of the set A given by (3). Its r_{ij} values for the attributes would depend upon the type of attribute scale used.

Expression (4) was defined as the description of an operation. However, it can be considered also as the description of the attributes required by an individual person to perform the operation. This dual interpretation of a description is important in interpreting some of the results obtained later. Because of the duality, it is occasionally necessary to identify what the description refers to -- an operation or an individual. When this is not necessary, the word "description" applies to both interpretations.

Up to this point a single O/A matrix has been the topic of discussion. However, a set of O/A matrices are present in the empirical situation of interest to us. Some of the operations are similar in any TS, but the majority of operations are different. This is also true for the set of O/A's. In addition, the number of operations can be different in each O/A in the set of O/A's. Generally the r_{ij} values in all of the O/A's are different. The attribute set, however, is assumed to be the same for each O/A. This assumption is not restrictive. If each O/A had a different attribute set, a new attribute set could be defined by combining all the attribute sets and calling this the common attribute set.

Before proceeding with the development of the model, a few general comments are appropriate on some of the issues involved in selecting attributes for the attribute set.

General Criteria for Selecting Attributes

It was pointed out in Part I that elementarity of operations is relative to a defined population. Elementarity is also relative to what we wish to accomplish with the TS. The number of operations in a TS is, practically speaking, determined as soon as the level of elementarity for operations has been selected. The only way the number of operations can be changed significantly in a TS is by altering the

elementarity of the operations. Selection of the number and nature of attributes is interrelated with the selection of operation elementarity, and both selections are governed by the objectives of the study.

In addition to the above considerations a number of other general and interrelated factors are involved in selecting attributes. These factors are considered desirable features for an attribute set to possess. These factors are here discussed only in general terms.

1. Measurability: An attribute can be measured very precisely and objectively, e.g., the height of a person in meters and centimeters, or it can be measured with no precision and only subjectively, e.g., "must have a sense of humor." However, the question of whether an attribute is measurable or non-measurable has to be answered by including time and cost considerations. For example, "must have a sense of humor" might well be a desirable attribute for people to have in nearly all group activities. It may be particularly desirable when the group is expected to perform in stress situations such as, combat operations. However, the attribute may be impractical (non-measurable) because of the time and cost involved in its determination, and because the attribute varies with ethnic and cultural background.

2. Relevancy: The relevancy of an attribute depends upon its importance or its criticality in the performance of a task. An attribute may be extremely relevant to accomplishing one task and totally meaningless when applied to another. Apart from this distinction, certain attributes have no relevance for any task. For example, "blue eyes" is an attribute for which it seems impossible to think of a task (in the Army) for which it might be required. Other attributes are non-relevant by law or regulation. Thus, the attributes "sex" and "race" are not permitted as descriptors for most or all Army tasks. On the other hand, the set of attributes should be large enough to describe every operation in a TS. For example, TS_3 "Constructing Azimuth Indexes", includes 55 operations. It does not appear reasonable to expect a set of three or four attributes to describe adequately all of the operations in this TS. Most questions about selecting relevant attributes are more subtle than the examples given above and are not easy to answer. One interesting method for obtaining answers to these questions is the Delphi-like technique of Roberts (1972). Clearly, relevancy is dependent on the purpose to which the TS descriptions are to be put, or the intent of the user.

3. Independence: In the model to be developed the attributes are assumed to be logically independent. The reason for this is that if attribute a_i and attribute a_j are not independent, then the presence of a_i and the absence of a_j in an operation amounts to a logical contradiction (Carnap, 1962). Independence is a logical requirement and sometimes difficult to achieve in practical situations. To illustrate the difficulty suppose one attribute to be "reading comprehension" and another "years of education." It is not immediately obvious whether these two attributes are logically independent or mutually dependent.

4. Interpretability: This factor is more of a requirement on the data structures derived from the O/A matrices than a requirement on the set of attributes. In other words, an extremely large set of attributes may be handled with the help of a computer, but the resulting data structures may be too large, complex and difficult to interpret and use.

The four desirable requirements interact with each other. One important relationship can be pointed out by considering the effect on relevance and interpretability caused by increasing the number of attributes. Certainly, increasing the number of attributes makes the descriptions of operations more complete and, hence, more relevant. But, doing this also makes the end results more difficult to interpret. In the extreme case the data handling requirements may come to exceed the capacity of even a large computer.

Issues raised in this section pose difficult problems, but no attempt can be made to resolve them within the present exploratory effort.

Attribute Scales

An attribute scale for each attribute is required before the r_{ij} values in an O/A matrix can be determined. If a binary scale is used, then an attribute is either present *in a description or absent*. With a binary scale each attribute has associated with it an arbitrary value (a cutting score) to determine whether a description does or does not possess the attribute. To illustrate, suppose the attribute is "arithmetic skill," and a value of 80 (on some scale) is the cutting score. Then a symbol -- say 1 -- is placed in the O/A matrix in the arithmetic skill attribute column for those desriptions requiring a score of 80 or higher. A different symbol -- say 0 -- is used *when the description does not* require a score of 80.

In general terms, the assignment of the symbols "1" and "0" to the r_{ij} values of the O/A matrix of Figure 2 is made by the following rule:

5) $$r_{ij} = \begin{cases} 1 & \text{if operation } o_i \text{ possesses attribute } a_j \\ 0 & \text{if operation } o_i \text{ does \underline{not} possess attribute } a_j. \end{cases}$$

When assignment rule (5) is applied to the operations and attributes of TS_{53}, as given in Table 4, the O/A matrix shown in Figure 3 is the result. This matrix is termed a binary O/A matrix, since a binary

Attributes

Operations	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}
o_2	1	1	0	0	0	0	0	0	0	0	0	0
o_3	1	1	1	1	0	0	0	0	0	0	0	0
o_4	0	0	0	1	1	0	0	0	0	0	0	0
o_5	0	0	1	1	1	0	0	0	1	0	0	0
o_6	0	0	1	1	1	1	0	0	1	0	0	0
o_7	0	0	1	1	1	0	1	0	0	0	0	0
o_8	0	0	1	1	1	1	0	1	1	0	0	0
o_9	0	0	0	1	1	0	0	1	0	0	0	0
o_{10}	0	0	0	0	1	0	0	0	0	0	0	0
o_{11}	1	0	1	1	0	0	0	1	1	0	0	0
o_{12}	1	0	1	1	0	0	0	1	1	0	0	0
o_{13}	0	0	1	0	1	0	0	0	1	0	0	0

Figure 3. Binary O/A Matrix for $(TS)_{53}$

attribute scale is used to construct it. To illustrate how this matrix is to be read consider operation o_5 as an example. It has a 1 in the four attribute columns a_3, a_4, a_5 and a_9. Thus, o_5 is said to be described by these four attributes. The absence in o_5 of the remaining eight attributes is descriptive, also, of the operation, but in a non-affirmative manner. It should be noticed that attributes a_{10}, a_{11} and a_{12} do not occur in any of the operations of TS_{53}. They occur in other TS, because we assumed that the 12 attributes were sufficient to describe all of the operations in the set of TS. The last three columns are dropped in versions of $(O/A)_{53}$ below, because they are redundant for TS_{53}.

Using a cutting score in descriptions creates a serious problem when applied to an O/A. A single cutting score has to serve for all the descriptions. This is a severe requirement, because it is not reasonable to expect a single score to be appropriate for all of the descriptions in the O/A.

A binary cutting score divides the attribute scale into two intervals. Thus one solution to minimize the problem is to divide the attribute scale into several intervals, that is, by introducing attribute levels (see, Kingsley and Kopstein, 1977). The refinement obtained is at the expense of adding attribute values and not by adding new attributes. Practical considerations may limit the size of the attribute set in an actual situation. If a size limitation exists, then finer attribute levels may require the elimination of desirable attributes from the attribute set.

A method allowing attributes to range over a possibly non-discrete set of values can overcome some of the defects of a binary cutting score. The theory of fuzzy subsets, developed by Zadeh (1965, 1973, 1977), offers an intuitively attractive basis on which such a method could be constructed[10/]. A few of the basic concepts of fuzzy subset theory are discussed in a later section of this report. Some ideas are also given on how the theory could be applied to empirical problems.

Problem Definition and Approach

In addition to other interests our concern is with inferring the structural properties of the information contained in an O/A matrix. More accurately, we are concerned with devisiing methods for detecting relations between the descriptions in an O/A matrix.

By definition the serial listing of descriptions in an O/A matrix exhibits the relation f descriptions being sequentially chained, and this is an example of a structural property. Other relations may exist, but their discovery is not as obvious and requires a sophisticated approach.

The approach adopted is to construct a mathematical model of the empirical situation represented by an O/A matrix. First, some simplifying assumptions are made and translated into mathematical terms. This approach has been initiated by our definitions of the sets O, A, the set of r_{ij} values, and by the definition of a description given by expression (4). Mathematical reasoning is then employed after these assumptions and tranlations have been made.

The information contained in an O/A matrix does not permit the use of statistical techniques to discover its structure. Statistical methods may possibly be used only to determine the r_{ij} values in the matrix.

The model presented in the next section is based on a simple binary scale. That is, the r_{ij} values in the O/A matrix are either 1 or 0. A model of this type has a number of advantages: (1) it can be used for the study of many empirical problems; (2) it is tractable and, thus, it provides insights to properties that are difficult to detect when a more complex model formulation is used; (3) it can be easily extended to include refinements of attribute levels; (4) it can be easily programmed for a digital computer.

The model presented is a first stage model. With it some problems are solved, others are not, and some ideas for a more refined version of the model are suggested.

[10/] Kaufmann (1975) gives a detailed summary of the development and status of research in the theory of fuzzy subsets.

THE BINARY VECTOR MODEL

The model to be discussed in this section was originally formulated in the language of set theory, symbolic logic and Carnap's (1962) concept of Q-predicate descriptions. However, to reach a wider audience the model is now presented in terms of binary vectors of a certain type. All of the concepts and results of the original formulation are preserved. In addition, the binary vector formulation is almost directly programmable for a digital computer.

Designation Vectors as Descriptions

Expression (4) was defined earlier to be the description of the arbitrary operation o_i in the general O/A matrix. When the r_{ij} values are binary, the descriptions are called binary vectors. For example, operation o_3 of Figure 3 is the binary vector with 9 components[11/],

$$(1, 1, 1, 1, 0, 0, 0, 0, 0).$$

Let $d(o_3)$ represent this vector so that

$$d(o_3) = (1,1,1,1,0,0,0,0,0).$$

No ambiguity results if the customary parentheses and commas of vector notation are eliminated. With this notational simplification, $d(o_3)$ becomes

$$d(o_3) = 111100000.$$

An arbitrary operation -- say o_i -- described by n binary attributes is designated by $d(o_i)$ and is a string of n 0's (zeros) and 1's. Following Homer (1967) such descriptions are termed designation vectors[12/]. With this notation the descriptions contained in Figure 3 for TS_{53} are written as designation vectors and shown in Figure 4.

$d(o_2)$	=	1 1 0 0 0 0 0 0 0
$d(o_3)$	=	1 1 1 1 0 0 0 0 0
$d(o_4)$	=	0 0 0 1 1 0 0 0 0
$d(o_5)$	=	0 0 1 1 1 0 0 0 1
$d(o_6)$	=	0 0 1 1 1 1 0 0 1
$d(o_7)$	=	0 0 1 1 1 0 1 0 0
$d(o_8)$	=	0 0 1 1 1 1 0 1 1
$d(o_9)$	=	0 0 0 1 1 0 0 1 0
$d(o_{10})$	=	0 0 0 0 1 0 0 0 0
$d(o_{11})$	=	1 0 1 1 0 0 0 1 1
$d(o_{12})$	=	1 0 1 1 0 0 0 1 1
$d(o_{13})$	=	0 0 1 0 1 0 0 0 1

Figure 4. Designation Vectors for TS_{53}

11/ Recall that attributes a_{10}, a_{11}, and a_{12} are not present in TS_{53}.

12/ Homer's designation vectors are an application of Ledley's (1960, 1962) "designation numbers."

Basic Operations with Designation Vectors

Components of the designation vectors (the 0's and 1's) are not ordinary integers but Boolean symbols, and the usual arithmetic properties do not hold. Three Boolean operations are used: addition, multiplication and complementation. These three operations are defined as follows:

<u>Addition</u>:

$$1 \oplus 1 = 1$$
$$1 \oplus 0 = 1$$
$$0 \oplus 1 = 1$$
$$0 \oplus 0 = 0$$

<u>Multiplication</u>:

$$1 * 1 = 1$$
$$1 * 0 = 0$$
$$0 * 1 = 0$$
$$0 * 0 = 0$$

<u>Complementation</u>:

$$1' = 0$$
$$0' = 1$$

The symbol " $\oplus$ " is used to indicate Boolean addition, and the symbol " * " to indicate Boolean multiplication. These special symbols are used to emphasize the distinction between Boolean and ordinary arithmetical operations.

Operations on designation vectors are defined in terms of these three basic Boolean operations. The general definitions are given first and then followed by an example using the designation vectors of Figure 4.

<u>Complementation</u>: The complement of a designation vector is obtained by replacing all 1's with 0's and all 0's with 1's in the vector. The complement of $d(o_i)$ is denoted by $\overline{d(o_i)}$ -- the bar being the Boolean operator NOT ($\overline{\quad}$).

Example: If

$$d(o_9) = 00110010,$$

then the complement of $d(o_9)$ is

$$\overline{d(o_9)} = 11001101$$

<u>Union</u>: For a 1 to appear in the i^{th} place of the union of two designation vectors $d(o_j)$ and $d(o_k)$, a 1 has to appear in the i^{th} place of $d(o_j)$ or $d(o_k)$ or both. Or, using Boolean arithmetic, add the two designation vectors component by component. The union is denoted by the symbol $\bigvee$ -- the Boolean operator OR ($\bigvee$)

Example: If

$$d(o_4) = 000110000$$
$$d(o_6) = 001111001,$$

then

$$d(o_4) \bigvee d(o_6) = 001111001.$$

<u>Intersection</u>: For a 1 to appear in the i^{th} place of the intersection of the two designaion vectors $d(o_j)$ and $d(o_k)$, a 1 must be present in the i^{th} place of, both, $d(o_j)$ and $d(o_k)$. Or, using Boolean multiplication, multiply the two designation vectors component by component. The intersection is denoted by the symbol $\bigwedge$ -- the Boolean operator AND ($\bigwedge$).

Example: If

$$d(o_{11}) = 101100011$$
$$d(o_3) = 111100000,$$

then

$$d(o_{11}) \wedge d(o_3) = 101100000.$$

Cardinality: The cardinality of a designation vector is the number of 1's in the vector and is denoted by $|d(o_i)|$.

Example: If

$$d(o_7) = 001110100$$

then

$$|d(o_7)| = 4.$$

The above basic operations on designation vectors are used to define more complex relations between them.

The Difference and Distance Between Two Descriptions

For a set of operation descriptions such as, the set of Figure 4, it is useful to be able to determine whether two descriptions are identical, and, if they are not identical, to determine the extent of their difference. By inspection $d(o_2)$ and $d(o_3)$ differ in all but the first two components. Also by inspection, it is easy to see that $d(o_{11})$ is identical with $d(o_{12})$. Although the difference between any two operations of Figure 4 is easy to determine, such determinations become rapidly more difficult when the attribute set or the set of operations is large. It is almost impossible to accomplish when both sets are large. However, a function can be defined for determining the difference between two descriptions.

Before defining this function, to avoid cumbersome notation, let d_i represent the designation vector $d(o_i)$. No ambiguity results by adopting this notation, and the expressions to be developed are easier to read, because fewer parentheses are present.

With this notational simplification let

$$\mathrm{Diff}(d_i, d_j)$$

represent the function that determines the difference between the two designation vectors d_i and d_j and call this function the difference function. The function is given by the following formula,

6) $$\mathrm{Diff}(d_i, d_j) = (d_i \vee d_j) \wedge \overline{(d_i \wedge d_j)},$$

where all the operations are Boolean. From this definition it is evident that $\mathrm{Diff}(d_i, d_j)$ is again a string of 0's and 1's. The following properties can be shown to hold for this string. If the k^{th} symbol is 1, then either the k^{th} symbol in d_i is 1 and the k^{th} symbol in d_j is 0, or the k^{th} symbol in d_i is 0 and the k^{th} symbol in d_j is 1. In other words, the symbols in the k^{th} place of d_i and d_j do not match. If, on the other hand, the symbol in the k^{th} place in $\mathrm{Diff}(d_i, {}_j)$ is 0, then either the k^{th} symbols in d_i and d_j are both 0 or both 1. In other words, the symbols in the k^{th} place of d_i and d_j match.

Two examples of the use of formula (6) are given to illustrate its use.

Example 1: If,

$$d_3 = 111100000$$
$$d_{11} = 101100011,$$

then

$$d_3 \bigvee d_{11} = 111100011,$$

and

$$d_3 \bigwedge d_{11} = 101100000,$$

so that

$$\overline{d_3 \bigwedge d_{11}} = 010011111.$$

Writing $\overline{d_3 \bigwedge d_{11}}$ underneath $d_3 \bigvee d_{11}$ makes it simpler to form this intersection. Thus,

$$\begin{aligned} d_3 \bigvee d_{11} &= 111100011 \\ \overline{d_3 \bigwedge d_{11}} &= 010011111 \end{aligned}$$

so that

$$\mathrm{Diff}(d_3,\ d_{11}) = 010000011.$$

In other words, the attributes a_2, a_8 and a_9 do not match in the two descriptions. The cardinality of $\mathrm{Diff}(d_3, d_{11})$ or $|\mathrm{Diff}(d_3, d_{11})| = 3$ is the number of attributes not matching.

Example 2: If,

$$\begin{aligned} d_5 &= 001110001 \\ d_6 &= 001111001 \end{aligned}$$

then, proceeding as in the first example,

$$\begin{aligned} d_5 \bigwedge d_6 &= 001110001 \\ \overline{d_5 \bigwedge d_6} &= 110001110 \\ d_5 \bigvee d_6 &= 001111001 \\ \mathrm{Diff}(d_5,\ d_6) &= 000001000 \end{aligned}$$

In other words, the only mismatched component in the two descriptions is attribute a_6. Finally, to finish the example,

$$|\mathrm{Diff}(d_5,\ d_6)| = 1.$$

The complement of the difference function, denoted by $\overline{\mathrm{Diff}}(d_i, d_j)$, is the vector that shows which attributes match. The cardinality of $\overline{\mathrm{Diff}}(d_i, d_j)$ gives the number of matching components. Using the last two examples,

$$\overline{\mathrm{Diff}}(d_3,\ d_{11}) = 101111100$$

with cardinality 6, and

$$\overline{\mathrm{Diff}}(d_5,\ d_6) = 111110111$$

with cardinality 8.

Before proceeding two special designation vectors need to be defined: the null vector and the unit vector. Let $d(\emptyset)$ represent the null designation vector. By definition $d(\emptyset)$ consists entirely of a string of 0's. The complement of $d(\emptyset)$, denoted by $d(U)$, is the unit vector and consists entirely of a string of 1's.

It can be shown that two designation vectors, say d_i and d_j, are equivalent <u>if and only if</u> their difference is the null designation vector. In symbolic notation, $d_i = d_j$ if and only if

7) $$\mathrm{Diff}(d_i,\ d_j) = d(\emptyset) = d_\emptyset.$$

The **theorem** is illustrated by using (6) to compare d_{11} and d_{12},

$$d_{11} = 101100011$$
$$d_{12} = 101100011.$$

Thus,

$$d_{11} \wedge d_{12} = 101100011$$
$$\overline{d_{11} \wedge d_{12}} = 010011100$$
$$d_{11} \vee d_{12} = 101100011$$

and

$$\mathrm{Diff}(d_{11}, d_{12}) = 000000000$$

so that

$$d_{11} = d_{12}.$$

The equivalence of d_{11} and d_{12} is readily established, but this example does not illustrate the power of the theorem given by expression (6). It is important, at least for simplification purposes, to identify equivalent descriptions in a TS. Equivalent descriptions occur in a TS in two ways. First, an operation may be repeated a number of times. For example, the operation denoted verbally as "place pin into firing chart..." occurs very frequently in the TS associated with FDC activities. Second, two or more operations may be denoted with different verbiage but have the same descriptions in terms of attributes. Some idea of the difficulty involved in determining equivalent descriptions in a TS can be obtained by considering TS_{04} "Constructing Deflection Indexes," which contains 59 operations. If each operation is described in terms of attributes by a designation vector, then $59^2 - 59 = 3422$ pairwise comparisons are required to identify equivalent descriptions. Clearly, this number of comparisons cannot be done manually even if the number of attributes is small. The difficulty becomes increasingly worse as the cardinality of the attribute set increases.

The difference between two designation vectors is closely related to the concept of the distance between two designation vectors. In fact, it can be shown that the cardinality of the difference function of two designation vectors has the essential properties of Euclidean distance[13/]. That is, if d_i, d_j, and d_k are three arbitrary designation vectors, then the following three properties hold. First, $|\mathrm{Diff}(d_i, d_j)| = |\mathrm{Diff}(d_j, d_i)|$ and this is the symmetric property of distance. Second, $d_i = d_j$ if and only if $|\mathrm{Diff}(d_i, d_j)| = 0$, and this is the identity property of distance. Third, $|\mathrm{Diff}(d_i, d_j)| + |\mathrm{Diff}(d_j, d_k)| \geq |\mathrm{Diff}(d_i, d_k)|$, and this is the triangle property of distance. In topology these three properties define a metric, i.e., the cardinality of the difference function has the essential properties of distance (Sierpinski, 1952; Kuratowski, 1962).

The Concept of Dominance

By inspecting the descriptions given by the designation vectors in Figure 4 it is easy to see that certain operations require more attributes than others. This is readily determined by comparing the cardinalities of the designation vectors. What is not so easy to determine is illustrated by the two descriptions,

$$d_3 = 111100000$$
$$d_2 = 110000000$$

from Figure 4. Description d_3 has the same attributes as description d_2 plus two more. Thus, an individual who can perform operation d_3 has attributes a_1, a_2, a_3 and a_4 and can certainly also perform d_3 which requires only two attributes a_1 and a_2. The terminology d_3 dominates d_2 is used to describe this situation, and the notation d_3 Dom d_2 will be used to represent it symbolically. This

[13/] See Restle (1954) for another psychological application of the cardinality of the difference function.

intuitive concept is more precisely defined by saying that d_i Dom d_j *if and only if the designation* vector d_i possesses all of the attributes of designation vector d_j plus at least one more. To determine visually whether one designation vector dominates another is impossible when the attribute set is large. However, the comparison can be done by using the following theorem. Designation vector d_i dominates designation vector d_j if and only if,

8) $$\mathrm{Diff}(d_i, d_j) = d_i \wedge \overline{d_j}.$$

Descriptions d_3 and d_2 are used to illustrate the application of expression (8). The left side of (8) is evaluated as,

$$d_3 \wedge d_2 = 110000000$$

$$\overline{d_3 \wedge d_2} = 001111111$$

$$d_2 \vee d_3 = 111100000$$

so that

$$\mathrm{Diff}(d_3, d_2) = 001100000.$$

The right side of (8) is evaluated as,

$$d_3 = 111100000$$

$$\overline{d_2} = 001111111$$

$$\overline{d_2} \wedge d_3 = 001100000,$$

and this is the same as $\mathrm{Diff}(d_3, d_2)$ so that d_3 Dom d_2.

It can be shown that the dominance relation induces a partial order on the set of descriptions. That is, the dominance relation is irreflexive, asymmetric and transitive. In other words, if d_i, d_j and d_k are three arbitrary descriptions, then it is false that d_i Dom d_i (Dom is irreflexive); if d_i Dom d_j, then it is false that d_j Dom d_i (Dom is asymmetric); and if d_i Dom d_j and d_j Dom d_k, then d_i Dom d_k (Dom is transitive). The partial ordering of the set of descriptions by the dominance relation is an important result. It is the first structural result derived from the model, and with it the set of descriptions can be arranged into a pattern.

Representations of the Dominance Relation

Two representations are used to exhibit the structure in a set of TS implied by the dominance relation, a matrix representation and a graph representation. Figure 5 is the first step in constructing the matrix representation. It is actually Figure 3 slightly rearranged. The descriptions are now listed in descending order of magnitude of their cardinalities. Cardinalities of the descriptions are shown in the column on the right-hand side of the matrix. The matrix of Figure 6 is obtained by using expression (8) on the descriptions in Figure 5. A total of 78 applications of (8) are required. For example, using (8), d_8 is compared with 11 descriptions to determine dominance, d_6 is compared with 10 descriptions, etc. If in these comparisons d_i dominates d_j, a 1 is placed in the i^{th} row and j^{th} column of the matrix. Descriptions d_{11} and d_{12}, being identical, are grouped together in the matrix. Thus the descriptions in the left-hand column dominate the descriptions in the top row if and only if a 1 appears in the corresponding row/column cell of the matrix. For example, d_8 dominates d_6, d_5, d_9, d_{13}, d_4 and d_{10}; d_7 dominates d_4 and d_{10}, etc. The matrix of Figure 6 is termed the dominance matrix associated with a TS. In particular, Figure 6 is the dominance matrix associated with TS_{53}. Row sums and column sums are given in Figure 6 as well as the cardinalities of the descriptions. A row sum is the number of descriptions dominated by the row description (e.g., d_8 dominates 6 descriptions, d_7 dominates 2 descriptions, etc. A column sum is the number of descriptions dominating the column descriptions

Designation Vectors	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	Cardinality
d_8	0	0	1	1	1	1	0	1	1	6
d_6	0	0	1	1	1	1	0	0	1	5
d_{11}	1	0	1	1	0	0	0	1	1	5
d_{12}	1	0	1	1	0	0	0	1	1	5
d_3	1	1	1	1	0	0	0	0	0	4
d_5	0	0	1	1	1	0	0	0	1	4
d_7	0	0	1	1	1	0	1	0	0	4
d_9	0	0	0	1	1	0	0	1	0	3
d_{13}	0	0	1	0	1	0	0	0	1	3
d_2	1	1	0	0	0	0	0	0	0	2
d_4	0	0	0	1	1	0	0	0	0	2
d_{10}	0	0	0	0	1	0	0	0	0	1

(Column group header: Attributes)

Figure 5. Figure 3 Rearranged by Cardinalities

Dom	d_8	d_6	d_{11} d_{12}	d_3	d_5	d_7	d_9	d_{13}	d_2	d_4	d_{10}	Cardinality	F S
d_8		1			1		1	1		1	1	6	
d_6					1			1		1	1	5	4
d_{11} d_{12}												5	0
d_3									1			4	1
d_5								1		1	1	4	[illegible]
d_7										1	1	4	[illegible]
d_9										1	1	3	2
d_{13}											1	3	1
d_2												2	0
d_4											1	2	1
d_{10}												1	0
Column Sums		1			2		1	3	1	5	7		

Figure 6. Dominance Matrix for TS_{53}

e.g., no descriptions dominate d_{11}, d_{12}, but five descriptions dominate d_4.

Not all descriptions are comparable. It is possible to have two descriptions, say d_i and d_j, where d_i is not equivalent to d_j, d_i *does not dominate* d_j, and d_j does not dominate d_i. That is, the two descriptions cannot be compared for dominance. This always occurs when the two descriptions have the same cardinality, or when expression (8) is not satisfied. Non-comparable descriptions are indicated by empty row/column cells in the matrix of Figure 6.

Figure 7 shows the dominance relation of Figure 6 as a graph. To construct the graph the procedure is first to plot descriptions of equal cardinality as points on the same level in descending magnitude and labeled with the appropriate d_i's. Then two points, d_i and d_j, are connected with a line if and only if a 1 is in the i^{th} row and j^{th} column of the dominance matrix. The graph of Figure 7 is called the dominance graph of TS_{53}. Such graphs, when a large number of descriptions are involved, can be extremely complicated, difficult to draw and difficult to read. Fortunately, some simplification

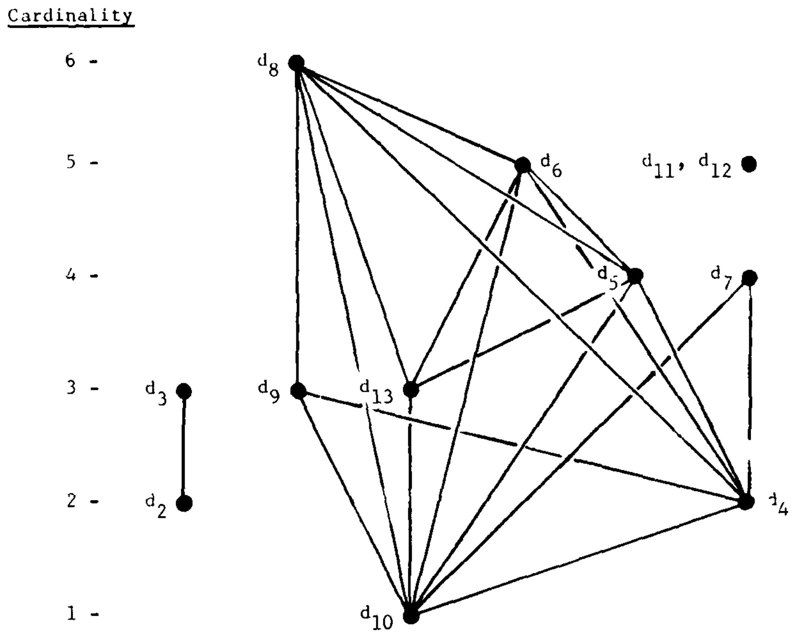


Figure 7. Dominance Graph of TS_{53}

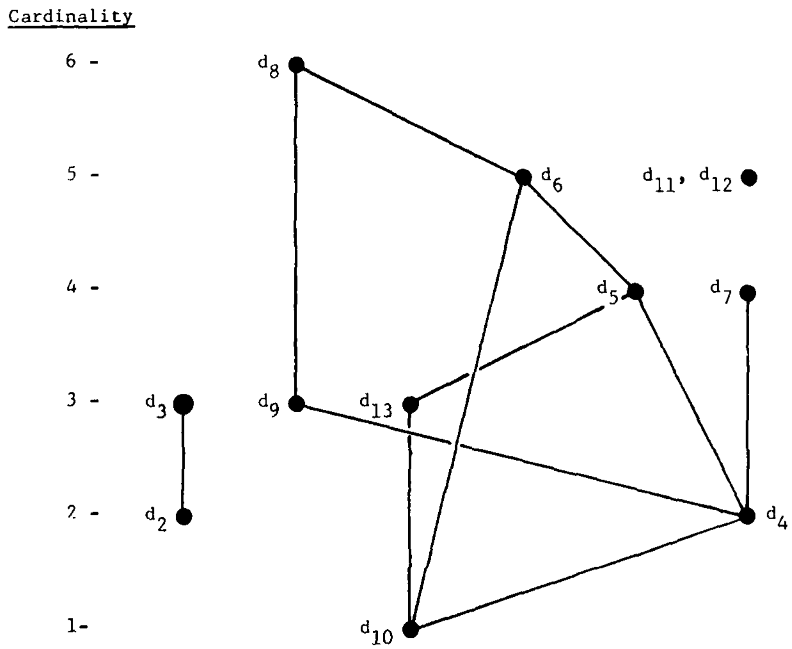


Figure 8. Dominance Graph of TS_{53} with Transitive Lines Removed

can be made by taking advantage of the transitivity of the dominance relation to remove redundant lines from the graph. For example, in Figure 6, d_8 dominates d_3 and d_3 dominates d_{10} so that by transitivity d_8 dominates d_{10}. Thus the line joining d_8 to d_{10} is redundant. An algorithm for removing such redundant lines from a transitive graph is given in Kingsley and Kopstein (1977). Applying this algorithm to the dominance graph of Figure 7 yields the simpler dominance graph shown in Figure 8.

The dominance matrix of Figure 6 and the dominance graphs of Figures 7 and 8 are different representations of the same underlying relation, namely the dominance relation. Each representation shows the relation in a different way. Dominance graphs show the relation graphically, and thereby dramatically depict the dominating descriptions and their interconnections. However, such depictions become extremely complicated to draw and interpret for large data sets. Dominance matrices are relatively easy to produce and can be manipulated mathematically, but they do not readily show the interconnections. Unlike graphs the matrices can be stored in a computer and then easily manipulated to produce any result of interest.

APPLICATIONS

A number of requirements are placed on the analyst who applies the quasi-algorithmic approach outlined in Part I of this report to establish TS and to use the model developed in Part II. First, he is forced to identify specifically the operations in the task being analyzed. Second, describing the operations forces him to select a specific set of attributes. Third, from the set of attributes he has to select exactly those attributes associated with each operation in the set of TS. However, the clarity forced on the analyst by these requirements is almost totally negated, if the analyst does not know in quite precise terms just what problem he is being asked to solve.

Some preactical interpretations of the mathematical model have been given as the model was being developed. The choice of terms used to describe concepts in the model was not arbitrary. The exclusive sum, metric and partial order are the customary terms used technically (in mathematics) to describe what we have termed difference, distance and dominance respectively. Our choice of terms to describe concepts reflects implicit applications of the concepts. Since we are here not solving a particular problem of application, we cannot give a detailed application of the model. In other words, the last requirement for clarity is violated (missing). The best that can be done under these circumstances is to discuss briefly and in general terms some possible uses of the model.

Applications to Training and Evaluation

A number of uses of TS for FDC tasks have been described in Part I. These uses were based on the serial listing of the operations in a task specification. However, the structure given by the model disrupts the serial relation of the operations and replaces it with other relations. These new relations disclose properties not immediately evident from a TS. Some of them are discussed below.

The dominance graph of Figure 7 can be used as a diagnostic tool either during instruction in the task, or in monitoring task performance and mastery. To illustrate, the performance of operation o_5 directly requires attributes needed in performing o_6. Thus failure to perform o_5 can be immediately compared with the performance of o_6. If the difficulty is not resolved, then o_8, which immediately dominates o_6, can be used for comparison. Longer and more complex back-tracking may be required for other troublesome operations of lower cardinality. Isolated components of the graph such as, d_{11}, d_{12} and d_3, d_2 of Figure 7 require special attention, because they are not dominated by or dominate other operations.

Use of the difference relation to identify equivalent descriptions has been mentioned earlier. The identification of equivalent operations is important, because it may be used to reflect the degree of practice in some particular facet of skill that is provided by a given task. Alternatively it can be used to pinpoint the repeated opportunities for observing this skill facet.

Cardinalities, row sums and column sums of descriptions are useful summary measures. From Figure 6, for example, it may be seen that o_8 dominates six other operations, and it also has the greatest number of attributes. Thus operation o_8 can be said to be critical for the performance of TS_{53}. Operation o_6 is the next most critical operation in the sense that it demands many attributes and influences a great many operations in TS_{53}. Column sums can be used, also, to identify critical operations. Those operations whose column sums are zero are critical, because they are dominated by other operations.

Of course, it must be remembered that these deductions from the model are hypothetical and for purposes of illustration only, since the attributes in the designation vectors are themselves hypothetical.

Generality of the Model and Other Applications

It will be recalled that the difference between two designation vectors, especially the cardinality of the difference function equates with their distance. Thus the basis for a classificatory system -- a taxonomy -- is provided. The greater the distance between two operations the less related they are, and vice versa. The degree to which two operations are related or similar is stated objectively and quantitatively by their distance. In principle, this way of stating relationships or similarities is parallel to the Linnaean taxonomic system applied in biology. The taxonomic classification is not limited to operations, but has a far more general applicability as explained below.

The model discussed here above is a specific application of a more general model. In this general model operations are replaced by "objects" and attributes by "characteristics." Thus the model includes any set of objects that can be described by the possession of characteristics from a pre-selected set of characteristics. (An object, in this sense, is a logical one and not necessarily a physical object.) As a result the areas of application of the model are diverse. Limits on its uses are those given previously in the discussion of the problem of selecting a set of attributes. Some applications to other problems of Army interest are shown in Table 5.

Table 5

Potential Applications of the Model

Objects	Characteristics
Missions	Tasks
Duty assignments	Duty modules
Duty positions	Duties
Career fields	MOS's
MOS's	Duties
Teams	Activities

In summary, the model is applicable to any clearly defined set of objects that can be described in terms of a finite set of characteristics. What can be deduced from such a model (over and above what has been illustrated here) depends on the particular area of application and on the specific problems addressed.

The dual meaning of a description was mentioned earlier but not illustrated. It will be recalled that a description can describe an operation or an individual. This duality might be useful when considering a single operation, but it is more useful when the entire TS is considered or a cluster of TS. Unfortunately the binary model is probably too gross for sensitive analysis of the latter situation. In Figure 4 a description of TS_{53} can be deduced to be

$$d(TS_{53}) = 111111111000.$$

In this description, it will be recalled, the last three attributes of the attribute set were not found in TS_{53}. Another task description, say TS_i, might include some of the last three hypothetical attributes so that its description might be

$$d(TS_i) = 111001100011.$$

Similar descriptions can be derived for all of the TS in the set for any individual. Using this set of descriptions together with the model reveals structures of the set of task descriptions for an individual. This is a gross method. The more sensitive method based on fuzzy subset theory is outlined in the next section.

FUZZY SUBSETS

In the earlier discussion of the deficiencies of a binary attribute scale we suggested that the theory of fuzzy subsets appeared to be a method for reducing these deficiencies. An introduction to some of the basic concepts of fuzzy subset theory is given in this section along with examples of the concepts. In addition, an outline is sketched to show how the concepts can be applied to describe a TS and a set of TS.

It will be recalled that a primitive notion in classical set theory is that of an element being a member of a set. An element is either a member, or it is not. No other alternatives are permitted. In contrast to this notion most of the sets in the real, empirical world do not have sharp boundaries that separate those objects that belong to a set from those that do not. For sets with fuzzy (not sharply defined) boundaries an element may have a grade of membership that lies somewhere between full membership and non-membership. For example, the set of individuals who are tall is a fuzzy subset of some reference set of individuals. Fuzziness is introduced by the vague word "tall." Because no clear cut boundary is given, it is not possible to arrive at an absolute agreement about membership in this subset of an individual who is 5 feet and 11 inches tall. However, such a person would have a higher degree of membership in the subset than an individual who is 4 feet and 8 inches tall. Continuing this same example Figure 9 gives the heights (in inches) of a reference set of eight persons and the fuzzy subset of "tall individuals." It is seen that each individual is assigned a <u>degree</u> of membership in the fuzzy subset. Degrees of membership range from 0 (non-membership) to 1 (full membership). Assignment of grades of membership allows a mathematical structure to be established that can be used to manipulate poorly defined concepts (e.g., "soft skills") for which membership in a subset is somewhat hierarchical.

Reference Set	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8
Height (inches)	53	72	68	73	77	55	84	63
Fuzzy Subset	0	.9	.6	.9	1.0	.2	1.0	.3

Figure 9. <u>Example of a Membership Function</u>

A more rigorous definition of a fuzzy subset begins with a reference set A whose elements are a_1, $a_2, \ldots, a_n$. This set is not fuzzy and its elements are well defined. Following Kaufmann (1975) fuzzy subsets of A will be indicated by a wavy line under the symbol of the subset. A fuzzy subset $\underset{\sim}{o}_1$ of A is characterized by a membership function associating with each a_i in A a number in the closed interval from 0 to 1 representing the grade of membership of a_i in $\underset{\sim}{o}_1$. Returning to the example shown in Figure 9, the last line shows individuals a_5 and a_7 definitely belong to the set of tall persons, and a_1 definitely does not. The remaining individuals have varying degrees of belonging to the subset.

All of the basic set theoretic operations of classical set theory can be reformulated for fuzzy subsets. To illustrate the potential of fuzzy subset theory we only need to define the operation of the union of two fuzzy subsets. Figure 10 is the example used to illustrate the definition. In this example

	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
$\underset{\sim}{d}_2$	.8	.7	.3	0	.1	.2	.4	.1	.3
$\underset{\sim}{d}_3$	.6	.5	.7	.7	.3	.1	.4	.2	.4
Union	.8	.7	.7	.7	.3	.2	.4	.2	.4

Figure 10. <u>Example of the Union of Two Fuzzy Subsets</u>

the first two rows are operations of TS_{53} and are described by an assumed membership function. The two descriptions $\underset{\sim}{d}_2$ and $\underset{\sim}{d}_3$ are called fuzzy descriptions. If $\underset{\sim}{d}_2 \cup \underset{\sim}{d}_3$ designates the union of the two fuzzy descriptions, then the membership function of $\underset{\sim}{d}_2 \cup \underset{\sim}{d}_3$ is defined as the maximum of the two membership functions of $\underset{\sim}{d}_2$ and $\underset{\sim}{d}_3$.

It is instructive to compare the fuzzy union of Figure 10 to the comparable operation $d_2 \vee d_3$ on the designation vectors of Figure 4, which is given by

9) $$d_2 \vee d_3 = 111100000.$$

The first four attributes in (9) all have the same value 1, but in Figure 10 there is a difference between these attributes. Likewise the last five attributes in (9) all carry weight 0, whereas the fuzzy union shows differences. This short example demonstrates the increase in sensitivity that is gained by using fuzzy subset descriptions.

The definition of the union of two fuzzy descriptions extends to any finite number of fuzzy descriptions. This suggests one way to summarize an O/A matrix of a TS when it is formulated in terms of fuzzy descriptions. Figure 11 is a hypothetical example to illustrate this summarization. The example is based on TS_{53} and the designation vectors of Figure 4. Assumed values of the membership function are chosen arbitrarily. The only rule followed is: where a 1 appears in the designation vector in Figure 4, a membership value greater than or equal to .5 is given to the corresponding location in the fuzzy description; where a 0 appears in Figure 4, a value less than .5 was selected for insertion into the corresponding location in the fuzzy description.

	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
d_2	.8	.7	.3	0	.1	.2	.4	.1	.3
d_3	.6	.5	.7	.7	.3	.1	.4	.2	.4
d_4	.3	.1	.2	.6	.7	.3	.4	.3	.3
d_5	0	0	.5	.7	1.0	.4	.1	0	.6
d_6	.1	.2	.6	.5	.8	.9	0	0	.8
d_7	.3	0	.5	.7	.9	0	.5	.2	.1
d_8	.4	.4	.8	.7	.9	1.0	.4	.5	.7
d_9	.3	.2	0	.6	.5	0	.2	.5	.4
d_{10}	0	0	0	.1	.9	.1	.2	.4	.4
d_{11}	.9	0	.6	.7	0	0	.4	.5	.8
d_{12}	.9	.1	.6	.7	.2	.4	.3	.5	.8
d_{13}	0	.4	.9	.3	.6	.2	.1	0	.5
Union	.9	.7	.9	.7	1.0	1.0	.5	.5	.8

Figure 11. TS_{53} Fuzzy Description and Summarization

In Figure 11 the union is a summary fuzzy description of the nine hypothetical attributes required to perform TS_{53}. Let $\underset{\sim}{d}(TS_{53})$ denote this description and $d(TS_{53})$ the summary description derived from Figure 4. These two descriptions are shown in Figure 12. In it exact matches exist only for a_5 and a_6, and the remaining attributes differ in various degrees. This example illustrates the increased

	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
$\underset{\sim}{d}(TS_{53})$	.9	.7	.9	.7	1.0	1.0	.5	.5	.8
$d(TS_{53})$	1	1	1	1	1	1	1	1	1

Figure 12. Comparison of Descriptions

sensitivity made possible when fuzzy descriptions are used. The fuzzy union of fuzzy descriptions in Figure 11 allows us to list the attributes in order of decreasing value as,

$$(a_5, a_6), (a_1, a_3), a_9, (a_2, a_4), (a_8, a_7),$$

where attributes with the same value are grouped by parentheses. Critical attributes are thus identified in the order of their criticality.

The definition of the union of fuzzy descriptions also suggests a method for comparing one TS with another. This can be done by calculating $d(TS_i)$ and $d(TS_j)$. In addition, if $d(TS_1)$, $d(TS_2, \ldots,$ $d(TS_n)$ are n summary fuzzy descriptions of n TS making up the job or duty position of a single individual, they can be compared two at a time. Finally, the fuzzy union of the n fuzzy summary descriptions can be formed to describe the individual's job or duty position.

It is intuitively obvious that a fuzzy model, similar to the binary model, can be devised. Many of the concepts of the binary model are easy to formulate in terms of fuzzy subsets, but others appear to involve some difficulties. It is known, for example, how to define a fuzzy relation, and this will permit a definition of fuzzy structures. The concept of dominance does not translate directly into fuzzy formulation, but instead several different notions of distance are available as well as several notions parallel to dominance. In this exploratory effort it was not possible to pursue these potentially useful and sensitive formulations.

REFERENCES

Ackoff, R. L., Scientific method: optimizing applied research decisions, New York: Wiley, 1962.

Ammerman, H. L. and W. H. Melching, The derivation, analysis and classification of instructional objectives, Technical Report 66 - 4, Alexandria, VA: Human Resources Research Office, 1966.

Banathy, B. H., Instructional systems, Palo Alto, CA: Fearon, 1968.

Burtt, H. E., Principles of employment psychology, New York: Harper, 1942.

Carnap, R., Logical foundations of probability (2nd ed.), Chicago: Univ. of Chicago Press, 1962.

Chambers, A. N., Development of a taxonomy of human performance: a heuristic model for the development of a classification system, AIR Technical Report No. 726-10/69-TR-4A, Silver Spring, MD: Amer. Institutes for Rsch., 1969.

Department of the Army, Personnel selection and classification: enlisted career management fields and military occupational specialties, AR 611-201, C9, (Jan 1978).

Department of the Army, Army training and evaluation program field artillery, 155 mm SP, direct support cannon units, ARTEP 6-365 (Dec 1976).

Department of the Army, Field artillery cannon gunnery, FM 6-40, C1, (Sep 1976).

Department of the Army, Modern battlefield cannon gunnery, FM 6-40-5 (Jul 1976).

Farina, A. J., Development of a taxonomy of human performance: a review of descriptive schemes for human task behavior, AIR Technical Report No. 726-1/69-TR-2, Silver Spring, MD: Amer. Institutes for Rsch., 1969.

Farina, A. J. and G. R. Wheaton, Development of a taxonomy of human performance: the task characteristics approach to performance prediction, AIR Technical Report No. 726/2035-2/71-TR-7, Silver Spring, MD: Amer. Institutes for Rsch., 1971.

Fine, S. A., A structure of worker functions, Personnel Guid. J., 1955, 34, 66 - 73. (a)

Fine, S. A., Functional job analysis, J. Personnel Admin. & Indust. Relat., 1955, 2, No. 1, 1 - 16. (b)

Fine, S. A., Functional job analysis as a method of indirect validation: a study in synthetic validity, Unpublished doctoral dissertation, The George Washington Univ., 1962.

Fine, S. A., A functional approach to a broad scale map of worker behavior, Paper presented at Amer. Psychol. Assn. Meet., Philadelphia, PA, September 1963.

Fine, S. A., An annotated bibliography of functional job analysis, McLean, VA: Human Sciences Rsch., 1965.

Hayes, D. P., L. Meltzer and G. Wolf, Substantive conclusions are dependent upon techniques of measurement, Behavioral Science, 1970, 15, 265 - 268.

Homer, E. D., On the computation of the number of elements in combinations of sets, Amer. Math. Monthly, 1967, 513 - 522.

Kaufmann, A., Introduction to the theory of fuzzy subsets, Vol. I, New York: Academic Press, 1975.

Kingsley, E. H. and F. F. Kopstein, Structuring occupational groupings from occupational descriptions, Technical Memorandum TM 77-1, Wayne, PA: IP-L, 1977.

Kuratoski, K., Introduction to set theory and topology, London: Pergamon, 1962.

Landa, L. N., Algorithmization in learning and instruction, Englewood Cliffs, NJ: Educ. Technol. Publ., 1974.

Landa, L. N., Instructional regulation and control: cybernetics, algorithmization and heuristics in education. Englewood Cliffs, NJ: Educ. Technol. Publ., 1976.

Ledley, R. S., Digital computers and control engineering, New York: McGraw-Hill, 1960.

Ledley, R. S., Programming and utilizing digital computers, New York: McGraw-Hill, 1962.

Levine, J. M. and W. H. Teichner, Development of a taxonomy of human performance: an information-theoretic approach, AIR Technical Report No. 726/2035-2/71-TR-9, Silver Spring, MD: Amer. Institutes for Rsch., 1971.

Levine, J. M., T. Romashko and E. A. Fleishman, Development of a taxonomy of human performance: evaluation of an abilities classification system for integrating and generalizing research findings, AIR Technical Report No. 726/2035-9/71-TR-12, Silver Spring, MD: Amer. Institutes for Rsch., 1971.

Mager, R. F., Preparing objectives for programmed instruction, San Francisco: Fearon, 1961.

Markov, A. A., Theory of algorithms, Moscow: Acad. of Sci. of the USSR, 1954. (Translation by Office of Technical Services, U. S. Dept. of Commerce, Washington, DC, Publ. No. OTS TT60-51085)

McCormick, E. J., Human factors engineering (3rd ed.), New York: McGraw-Hill, 1970.

McCormick, E. J., J. W. Cunningham and C. G. Gordon, Job dimensions based on factorial analyses of worker oriented variables, Personnel Psychol., 1967, 20, 417 - 430.

Miller, R. B., Development of a taxonomy of human performance: a user-oriented approach, AIR Technical Report No. 726/2035-2/71-TR-6, Silver Spring, MD: Amer. Institutes for Rsch., 1971. (a)

Miller, R. B., Development of a taxonomy of human performance: design of a systems-task vocabulary, AIR Technical Report No. 726/2035-3/71-TR-11, Silver Spring, MD: Amer. Institutes for Rsch., 1971. (b)

Miller, R. E., A comparison of some theoretical models of parallel computation, Trans. IEEE, 1973, C-22, 710 - 717.

Pask, G., Conversation, cognition and learning, New York: Elsevier, 1975.

Peterson, J. L., Petri nets, Computing Surveys, 1977, 9, 223 - 252.

Prien, E. P. and W. W. Ronan, Job analysis: a review of research findings, Personnel Psychol., 1971, 24, 371 - 396.

Restle, F., A metric and an ordering on sets, Psychometrika, 1959, 24, 207 - 220.

Roberts, F. S., Building an energy demand signed digraph I: choosing the nodes, Rand Corp. Rpt. R-9271/1-NSF, Sta. Monica, CA: Rand Corp., 1972.

Sierpinski, W., General topology, Toronto: Univ. of Toronto Press, 1952.

Simon, H. A., Identifying basic abilities underlying intelligent performance of complex tasks, Ch. 5 in L. B. Resnick (Ed.), The nature of intelligence, Hillsdale, NJ: Lawrence Erlbaum Assoc., 1976.

Smith R. G, The development of training objectives, Research Bulletin No. 11, Alexandria, VA: Human Resources Research Office, 1964. (a)

Smith, R. G., An annotated bibliography on the determination of training objectives, Supplement to Research Bulletin No. 11, Alexandria, VA: Human Resources Research Office, 1964. (b)

Teichner, W. H. and J. Whitehead, Development of a taxonomy of human performance: evaluation of a task-classification system for generalizing research findings, AIR Technical Report No. 726/2035-4/71-TR-8, Silver Spring, MD: Amer. Institutes for Rsch., 1971.

Theologus, G. C., Development of a taxonomy of human performance: a review of biological taxonomy and classification, AIR Technical Report No. 726-12/69-TR-3, Silver Spring, MD: Amer. Institutes for Rsch., 1969.

Theologus, G. C., T. Romashko and E. A. Fleishman, Development of a taxonomy of human performance: a feasibitlity study of ability dimensions for classifying tasks, AIR Technical Report No. 726-1/70-TR-5, Silver Spring, MD: Amer. Institutes for Rsch., 1970.

Theologus, G. C. and E. A. Fleishman, Development of a taxonomy of human performance: validation study of ability scales for classifying human tasks, AIR Technical Report No. 726/2035-4/71-TR-10, Silver Spring, MD: Amer. Institutes for Rsch., 1971.

Trakhtenbrot, B. A., Algorithms and automatic computing machines, Boston: Heath, 1963.

Vazsonyi, A., Geometry of information systems, Part I, Interfaces, 1977, 8, No. 1, 76 - 81.

Vazsonyi, A., Geometry of information systems, Part II, Interfaces, 1978, 8, No. 2, 88 - 94.

Watson, J. D., The double helix, New York: Atheneum, 1968.

Wheaton, G. R., Development of a taxonomy of human performance: a review of classificatory systems relating to task performance, AIR Technical Report No. 726-12/68-TR-1, Silver Spring, MD: Amer. Institutes for Rsch., 1968.

Zadeh, L. A., Fuzzy sets, Information and Control, 1965, 8, 338 - 353.

Zadeh, L. A., Outline of a new approach to the analysis of complex systems and decision processes, IREE Trans. on Systems, Man and Cybernetics, 1973, Vol. SMC-3, No. 1, 38 - 44.

Zadeh, L. A., Fuzzy sets and their application to pattern classification and clustering analysis, in J. VanRyzin (Ed.) Classification and clustering, New York: Academic Press, 1977.

Zisman, M. D., Use of production systems for modelling asynchronous, concurrent processes, in D. Waterman and F. Hayes-Roth (Eds.), Pattern directed inference systems, New York: Academic Press, 1978.